OIL SHALES OF KENTUCKY

THIESSEN – WHITE – CROUSE

The

Kentucky Geological Survey

WILLARD ROUSE JILLSON
DIRECTOR and STATE GEOLOGIST

SERIES VI
VOLUME TWENTY-ONE

Oil Shales of Kentucky
And Other Papers

1925

Photo by W. R. Jillson

AN OUTCROP OF THE DEVONIAN SHALE.

This exposure is located three miles west of Clay City, Powell County, Ky., on the Louisville and Nashville Railroad. It is about seventy-five feet in thickness and typical of the formation which here is much weathered.

OIL SHALES *of* KENTUCKY

A Series of Four Economic and Morphological Discussions of the Devonian Shales of this Commonwealth

BY

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Presented with Three Separate Geological Papers

BY

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CHARLES STEVENS CROUSE

Illustrated with Sixty-four Photographs Maps and Diagrams

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Preface

During the last few years a growing interest has been evinced in the lithological character and commercial possibilities of the black Devonian oil shales of Kentucky. This interest has been based upon the assumption that the oil reserves of the continental United States would very likely be considerably depleted and unable to meet the growing demand for natural petroleum within the next decade or two. The discussions of Kentucky's oil shale here presented have been so arranged as to answer the most important questions of the present time and may be regarded as a sequel to the writer's, "A Preliminary Report on the Oil Shades of Kentucky" which appeared in Series VI., Vol. II., Ky. Geol. Survey, in 1921.

There are also presented within these covers three excellent and timely papers dealing with the detailed and general geology of Kentucky by Professors Arthur M. Miller, Walter H. Bucher and Charles Stevens Crouse. These papers are separate and unrelated to the symposium on the Devonian Shales.

W. R. Jillson

Director and State Geologist.

Old State Capitol,
Frankfort, Ky.,
May 1, 1925.

Contents

Illustrations

Oil Shales *of* Kentucky

I.

MICROSCOPIC EXAMINATION OF KENTUCKY OIL SHALES*

By Reinhardt Thiessen

Introduction

A shale is generally defined as a rock formed by the consolidation of clay, mud, or slit, having a finely stratified, laminated, or fissile structure. When such a rock contains organic matter it is termed a carbonaceous shale, and if the organic matter be of such a nature that when the rock is heated it yields bituminous substances, it is called a bituminous shale. When rich in organic matter yielding tar, oil, and gas, such rocks are now called oil-shales.

Many such deposits are now known and have been described, and much has been said of their geologic occurrence, geology, properties, utilization, etc., but very little has been done and said concerning the origin, composition, and general characteristics of these substances. Various theories have been advanced to account for the occurrence and origin of oil shales, but most of them are vague and add little to the knowledge of their origin. It has long been known, or rather surmised, that the bituminous nature and dark color were due to organic matter contained in the rocks, for which both animal and plant matter have been held as responsible.

Previous Investigations

Up to the present time no comprehensive account of the composition, structure, and origin of the bituminous or oil shales is available; but little work appears to have been done in this direction.

The spore matter in these shales was first discovered, as far as can be learned, by Dr. H. A. Johnson and B. W. Thomas[1] of

*Published by permission of the Director U. S. Bureau of Mines.

[1] Johnson, H. W., and Thomas, B. W., "Microscopic organisms in the bowlder clays of Chicago and vicinity," Bull. Chicago Academy of Science, Vol. 1, No. 4, 1884, pp. 35-40.

the Water Supply Commission of Chicago. During 1865 to 1867, while constructing a tunnel for the purpose of supplying Chicago with water from Lake Michigan, they discovered yellow, amber-colored, flat, disc-like bodies, varying from 1/85 to 1/250 of an inch in diameter, in the bowlder clays through which the excavation was made. On completion of the tunnel, large numbers of the same discs were frequently observed in the precipitate of the city water supply. In 1881, when examining bowlder clays collected from the high cliffs on the shore of Lake Michigan. 20 miles north of the city, the same disc-like bodies were discovered. They were found both free in the clay, and in fragments and bowlders of shale in the clay. They were later found in the bowlder clays in many localities in and around Chicago, and were soon traced to their origin in the shales of the Devonian deposits of Illinois and other states.

On learning of this discovery, Dawson[2] looked for and found them also (1871) in the Devonian shale at Kettel Point, Lake Huron. He describes the shale as being studded with disc-like bodies, scarcely more than 1/100 of an inch in diameter. He believed them to be spore-cases, and proposed the name *Sporangites Huronensis,* but later,[3] believing that they were spore-carps of an ancient Salvinia, re-named them *Protosalvinia Huronensis.* When sections of the rock were made, he found its substance filled with these bodies. They appeared yellow-amber in color, and showed but little structure, except that the walls could be distinguished from the internal cavity. Dawson, it appears, made no discrimination between a number of different spores.

Edward Orton[4] of the Geological Survey of Ohio during the same period found the discs in the bituminous shales, at that time called the "Huron shales" of Ohio, and ascribed the bituminous character of the shale to these spores. After naming various fossils found in the shales—such as *Dadoxylon* and *Calamites*—he says that the former are of small account when compared with certain microscopic fossils that are with little doubt of vegetal origin, and which are accumulated in large num-

[2] Dawson, J. W., "On spore-cases in coals," Amer. Jour. Science, Vol. 1, 3rd Series. 1871, pp. 256-263.

[3] Dawson, J. W., "The Geological History of Plants," 1896.

[4] Orton, Edward, "A source of the bituminous matter of the black shales of Ohio," Proc. Amer. Assoc. Adv. Science, Vol. 31, pt. 2, 1882, pp. 373-384; Geol. Survey of Ohio, First Annual Rep., 1890, pp. 32-33; Geol. Rep. of Ohio, Vol. VII, 1893, p. 26.

PLATE I.—Cross section of oil shale of the Devonian of Boyle County, Kentucky (× 10), giving the general appearance at a low magnification. The white speckling represents spore coats and quartz grains. The spore coats may be recognized as linear specks and the quartz grains as small more or less irregular specks.

bers throughout the black beds of the entire shale formation, composing sometimes a noticeable proportion of the substance of the rock, and apparently giving origin to an important extent to the bituminous character of the bed. No further description was given beyond mentioning the spores and a few fossil plant fragments.

Conacher[5] examined the oil shales and torbanite of England and Scotland, and concludes that they are derived from the same substances as coal; but that in the shales there has been a much larger elimination of the woody matter, leaving a large proportion of resinous matter mixed with the sand.

[5] Conacher, H. R. J., Oil shales and torbanites, Trans. Geol. Soc., Glasgow, Vol. 15, pt. 2, pp. 164-192.

PLATE II.—Cross section of oil shale of the Devonian of Boyle County, Kentucky (× 10), with a larger amount of mineral matter.

Work of this kind tends to show that oil shales are of organic origin, and that the oil distilled from the shales is not contained in them as such, but is derived from plant parts and plant products which form part of the deposit. Other theories hold that the oil distilled from them is in the form of oil absorbed by the rock or clay. Of this theory, Cunningham-Craig[6] is the leading advocate. He believes that oil shales are absorptive phenomena, and that oil has an affinity for argillaceous deposits, the source of the oil being things of the past. Shales composed of alumina, silica, ferric hydroxide, and clays of the nature of Fuller's earth, he thinks, are impregnated with, or were impregnated with,

[6] Cunningham-Craig, E. H., Kerogen and kerogen shales, Jour. Inst. Petroleum Technologist, vol. 2, 1916, pp. 238-269. "The origin of oil shales," Proc. Roy. Soc. Edinburgh, Vol 36, 1916, pp. 44-86.

adventitious oils, the source of which has now disappeared. Oil shales, therefore, he concludes, are colloidal, the crude oil being the disperse phase, and the mineral matter and clay the dispersion medium. For all practical purposes, oil shales may be looked upon as very stable gels.

Cannel Coals, Boghead Coals and Torbanites

Certain deposits have been described in the past under the names of cannel coal, boghead coal, torbanite, kerosene shale, and tasmanite, without a clear distinction between them on the basis upon which they have been classified in the past. Since they have been used for the distillation of oils, it is well to bear them in mind at this time.

This group has received considerable attention in the past. A fairly complete review of the work done on them has been given by J. E. Carne,[7] with special references to the kerosene shales of New South Wales, Australia.

Sufficient evidence has lately been found upon which to base safe conclusions as to the origin and composition of this group.[8] The bituminous shales may be divided into several well defined classes according to their origin, among which the boghead coals occupy a definite place, distinct from all the others.

Kentucky Oil Shales

The following samples of oil shale, tabulated in table 1 of the Devonian of Kentucky,[9] furnished by W. R. Jillson, Director and State Geologist of the Kentucky State Geological Survey, together with data as to yields of oil and gas, were examined.

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[7] Carne, J. E., "The kerosene shales of New South Wales." Memoirs of the Geological Survey of New South Wales, Geology, No. 3, 1903.

[8] Origin of the boghead coals. Reinhardt Thiessen. Shorter contribution to General Geology. U. S. Geological Survey, 1924. In press.)

[9] Preliminary Report on the Shales of Kentucky. W. R. Jillson, Ky. Geol. Surv., Series VI, Vol. II, pp. 1-37, Frankfort, 1921.

TABLE I.

OIL AND GAS CONTENT IN THE DEVONIAN SHALE OF KENTUCKY

Number	County	Oil per ton, gallons	Gas per ton, cubic feet.
1	Rockcastle	8.00	3,000
2	Lewis	10.25	3,000
3	Boyle	11.00	5,000
4	Clark	11.00	5,000
5	Bath	11.25	3,000
6	Bullitt	11.50	8,000
7	Rowan	12.50	8,000
8	Jefferson	15.50	5,000
9	Lincoln	15.50	8,000
10	Marion	16.00	8,000
11	Powell	16.75	8,000
12	Taylor	27.75	10,000

General Description

The shales of the Devonian are mainly composed of three distinct constituents, namely, clay, organic matter and pyrite. These three constituents vary in proportion to the various samples, and from layer to layer—in the same sample, sometimes in close succession. In the samples examined, the clay forms by far the largest part as shown in table II, and may be said to form the base in which the other constituents are embedded.

The following table of shales from the various counties shows the amount of loss in weight on burning, and hence approximately the amount of organic matter and the mineral matter:

County	Organic matter, per cent	County	Organic matter, per cent
Taylor	30.73	Jefferson	23.33
Clark	30.00	Bullitt	20.44
Boyle	29.46	Powell	20.00
Lincoln	28.66	Lewis	19.39
Rowan	27.98	Rockcastle	15.00
Bath	26.12	Marion	12.98

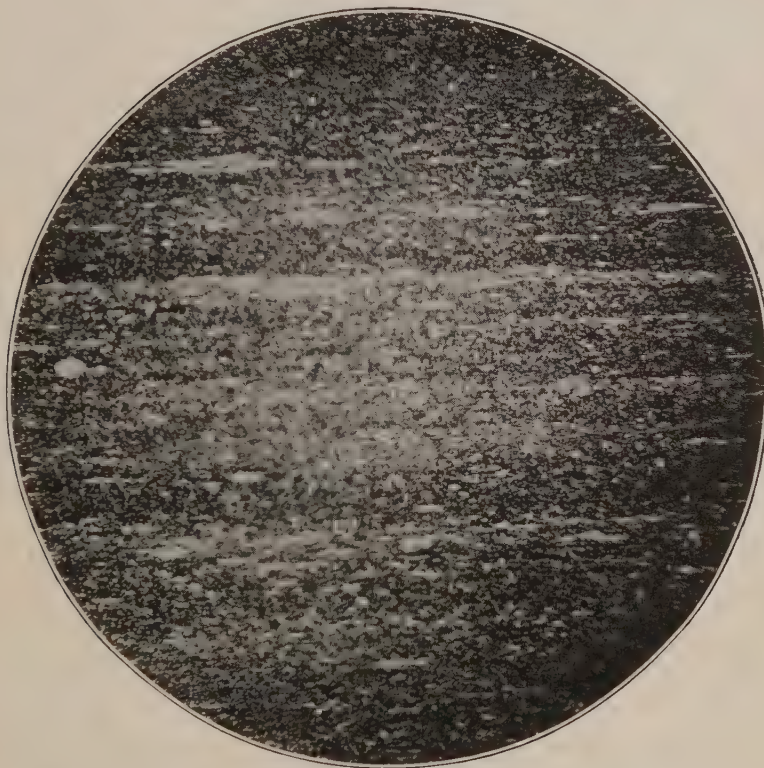

PLATE III.—Cross section of oil shale of the Devonian of Rock Castle County, Kentucky (× 10), showing a larger amount of mineral matter and laminations of richer and leaner layers.

This list is given in the descending order of the combustible contents of the samples. Since the determinations were made from rather small hand samples from each locality, the results may not give the average contents from each place. The microscopic appearance as a whole of the sections made from each sample harmonizes very well with the determinations.

The shales were examined microscopically through thin sections, both on horizontal and vertical sections; through thin sections after removing the mineral matter, leaving the organic matter; and through thin sections after removing the organic matter, leaving the mineral matter.

PLATE IV.—Cross section of oil shale of the Devonian of Rowan County, Kentucky (× 10), from a sample with about an average content of organic matter.

Appearance of Thin Sections Under the Microscope

Seen microscopically, by transmitted light, thin sections have a light, grayish-brown to dark brown appearance, the shade depending upon the proportion of organic to mineral matter in it—the more mineral matter the lighter its appearance. The degree of metamorphism of the organic matter also determines the color to a large extent. The more highly metamorphosed the shale the darker the appearance. Under low magnification, from 10 to 50 diameters, the sections show a brown background speckled with innumerable light specks, due to the larger grains of quartz and spore coats. (Plates I, II and III.) The quartz grains show up white and the spores yellow, together causing a dirty, grayish color. In the photographs, the spore walls are

shown as short linear specks, and the mineral matter as minute, more or less irregular, specks; and the brownish background is shown in dark or black. Most sections are uniform in this respect, except that some are lighter or darker than others, due to differences in the proportion of the mineral matter to organic matter; others are decidedly striated, as shown in Plate III, due to layers differing in the proportions of these constituents. The lighter striae represent layers richer in mineral matter.

The particles of pyrite cannot be distinguished at this magnification.

At a higher magnification, at 200 diameters, for example, many of the constituents begin to stand out more clearly. The brownish groundmass of the lower magnification is now largely resolved into a very heterogenous mass, consisting of particles of organic matter of all shapes and sizes, intermingled with fine quartz grains of all shapes and sizes dwindling down to invisibility. In this heterogenous mass, pyrite grains, spore walls and their fragments, and more highly carbonized fragments of plant cells and tissues, are imbedded in smaller or larger numbers and stand out sharply. Plates X, XII, XIV, XV, XVII, XVIII and XX show the characteristic appearance. The spores or their larger fragments are very easily distinguished on account of their clear yellow color. The more highly carbonized cell fragments are of a very dark brown to black color, usually linear, sharp-edged and sharp-cornered, and are particularly noticeable in horizontal sections; they are variable in number, but on the whole form but a small part of the total mass. The organic matter which constitutes the groundmass is not so easily defined at this magnification. It ranges from a dark brown to a light yellow color, and consists of very irregular fragments, usually flat, but otherwise of very irregular forms. The various shaped and variously colored particles are very intimately intermingled with each other and the mineral matter. Much of this is, however, clearly shown to be fragmented and disintegrated spore matter; some is clearly identified as cuticular matter; part of it consists of bits of plant tissues more highly carbonized; but part of the organic matter can not be classified as spore nor cuticular matter, but probably is of waxy and humic origin. The spore and cuticular matter constitutes the larger part. However,

PLATE V.—Cross section of oil shale of the Devonian of Taylor County, Kentucky (× 200), giving the appearance at a higher magnification. The spore walls are shown as collapsed rings or parts of rings; two types of spores are shown; thick and thin walled. The quartz grains are represented by more or less irregular white patches distributed through the groundmass between the spore. The groundmass is not all resolved into its constituents. The more or less rounded black spots represent pyrite particles.

the relative amounts of all the constituents are very variable, and in some sections but relatively few spores are noticed.

At very high magnification, 1,000 diameters or over, all of the groundmass—that is, matter lying between the larger constituents—is resolved into more or less definite constituents, and

only a small part being colloidally dispersed; and although not all determinable, is now shown to consist largely of laminated and plate-like particles or fragments, much distorted and crinkled. (Plates VI, IX, XI, and others.) Only a small part of this matter is directly recognizable as microspores, fragments of larger spores, and cuticles, a few diatom shells, and plant fibers. The remainder is not directly or indirectly determinable as spore matter, cuticular matter, and humic matter, while another part can as yet not be determined, and its origin can only be obtained by inference. In addition to the cerous coverings of spores and cuticles, plants contain a number of other substances equally resistant to decay, such as waxy coverings of leaves in the form of a bloom or fine hairs, phytosterine, fats and oils—of which no living cell is entirely free—terpines, camphors, aliphatic and cyclic corbohydrates, and a host of other equally resistant plant products. While these can not be directly recognized, they or their derivatives must still be present and constitute part of the groundmass. Relatively few microspores are seen, and these in a very poor state of preservation. It is very likely that a much larger number of microspores than can actually be identified contributed to the deposit but have lost their identity, and form a part of the general ceric constituent.

The organic matter, it must be understood, is intrabedded and interbedded with from three to eight times or more of mineral matter. Much of the mineral matter is so finely divided and so intimately associated with the organic matter that it can not be distinguished from it at the highest magnification possible. When, however, the mineral matter in the shale is in the form of particles large enough to be seen, it is more or less easily distinguished from the organic matter through their shape, color, transparency, and other physical characteristics. The pyrite, in particular, stands out sharply at a higher magnification as opaque, usually spherical, particles. (Plates IX, XI, and others.)

Many of the mineral particles, most of which are quartz, are aggregates of smaller particles; others are merely small lumps of clay matter, or aggregates of particles of or approaching colloidal sizes.

The brown or brownish-red colored organic matter photographs as black or dark gray, the same as the opaque more highly

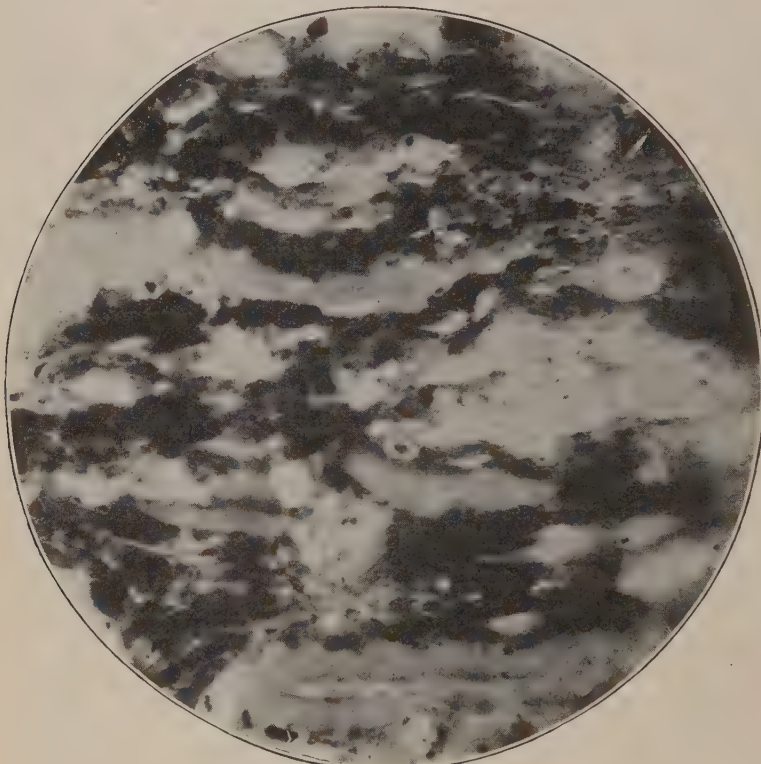

PLATE VI.—Cross section of oil shale from the Devonian of Taylor County, Kentucky (× 1000), showing the groundmass in detail. Microspores, fragments of spores, both in gray, clay masses and quartz grains, in white, very finely macerated organic matter of a brown color, in black, very thinly laminated organic matter, in white, and pyrite particles as rounded black masses, are shown.

carbonized particles, and becomes more pronounced in the photographs than it really is in thin sections.

Nature of the Organic Matter

All of the organic matter is in a colloidal state—that is, with an ultra-condenser it is shown to be composed of ultra-particles. This does not mean that it is in a formless condition. On the contrary, most of it is composed of more or less definite bodies of aggregates, each of which is in a solid colloidal condition, such as spores, parts of spores, fragments of cuticles, and other organic matter, and only a small part is colloidally dispersed. The

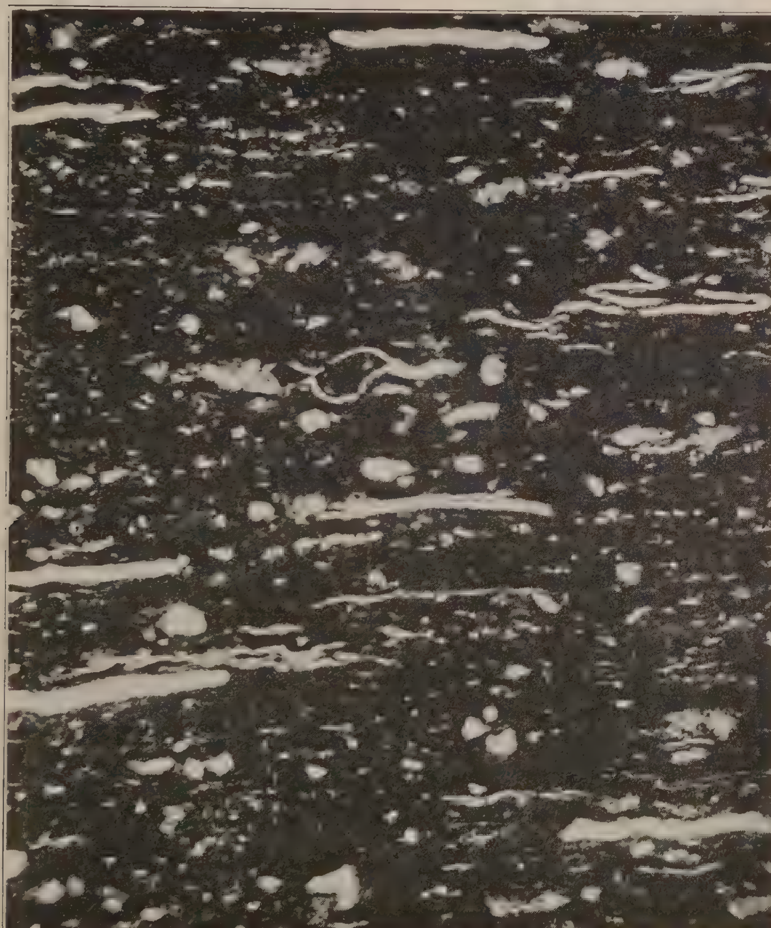

PLATE VII.—Cross section of oil shale of the Devonian of Clark County, Kentucky (× 200). Some thin walled spores and fragmented spores and a large proportion of mineral matter are shown; groundmass not well resolved. Pyrite particles shown as black spots.

spores are of clear light yellow color, and the organic matter of the embedding matrix is of a light yellow to dark brown or reddish-brown, all shades being intermixed.

All of the organic matter is very resistant to chemical reagents. Solvents dissolve very little or nothing of it; concentrated acids have little or no effect on it, or change the color but slightly. When treated for two weeks with Schulze's rea-

PLATE VIII.—Cross section of oil shale of the Devonian of Boyle County, Kentucky (× 200), showing a considerable number of thin walled spores and fragments of spores.

gent (30 per cent nitric acid in a saturated solution of potassium chlorate), only a relatively small but varying amount of solution is obtained when peptized with ammonia. When ordinary bituminous coals are treated with the same reagents at the same concentration and for the same period, and peptized with

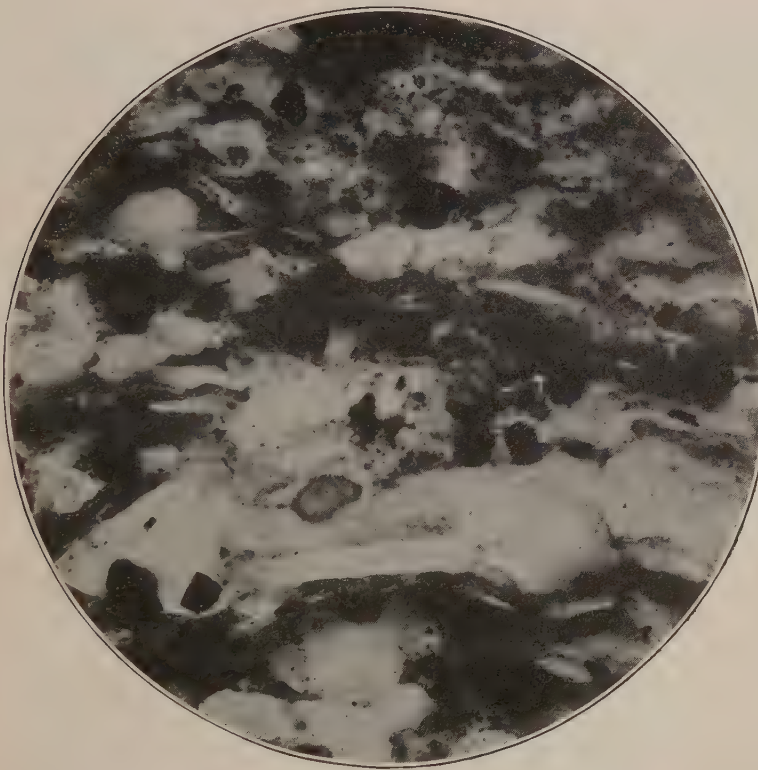

PLATE IX.—Cross section of oil shale of the Devonian of Boyle County, Kentucky (× 1000), showing the groundmass in detail. Microspores, fragments of spores, quartz grains, clay matter and a number of pyrite particles, in black, are well shown. The dark irregular areas represent organic matter mixed with clay matter.

ammonia, all the humic matter—that is, all the matter shown by the microscope to be of cellulosic or ligno-cellulosic origin, including the resinous matters—is dissolved, while the ceric matter—that is, the substance shown by the microscope to be spore matter, cuticular and related matter—remains undissolved, and to all appearances unchanged. This process roughly divides the organic matter into two classes, namely, the humic matter and the ceric matter. In the oil shales, as shown by this process, by far the largest part is insoluble matter, with only a small but varying proportion of the soluble matter intermixed. According to this process as well as through its appearance and behavior. In other respects it is shown that the soluble matter is

humic, and the insoluble matter is ceric. The latter is directly shown to be true, in that a large part consists of directly recognizable spore and cuticular matter. Also through its color and general appearance much of the degradation matter is inferred to be ceric.

The Spore Matter

When the shale is treated with hydrofluoric, nitric and hydrochloric acids, the remaining organic matter may easily be separated and spread out for examination. When thus treated it is also shown that it consists chiefly of spore and cuticular matter, unidentifiable ceric matter, and some unidentifiable humic matter. The spore matter consists of whole spores, fragments of spores, and finely macerated spore matter.

The whole spores and larger fragments can easily be picked out for individual examination. The largest number of the spores are comprised under one type. (Plates XXXVI and XXXVII.) They are of rather large but variable sizes, measuring approximately from 150 to 200 microns in diameter, and relatively thick. (1 micron=1/1000 millimeter, or approximately 1/25,000 inch.) The spores are flattened, and are in the form of discs of circular shape. Their outer surfaces have been changed considerably, and have suffered demarcation apparently through abrasions during the bog period and decomposition changes during the great period that has elapsed during and since the Devonian times. Nevertheless, some definite sculpturings have remained. The most conspicuous and easily recognized markings are a series of ridges on either side of the disc. Frequently they form a more or less circular ring on the discs and approximately parallel to the periphery, but with a spur connecting it with a similar ridge on the opposite side of the discs. Occasionally the ridges form radiating systems, and then again irregular designs. The ridges are evidently a part of the tetrasporic markings, and whatever their form or position, they are always of the same general nature. They are characteristic and persistent. Although these spores are poorly preserved and many of the exterior characters have disappeared, the system of ridges identifies them with spores in New Albany shales of Ohio, Indiana, and the chocolate shales of Illinois. In these, the tetrasporic

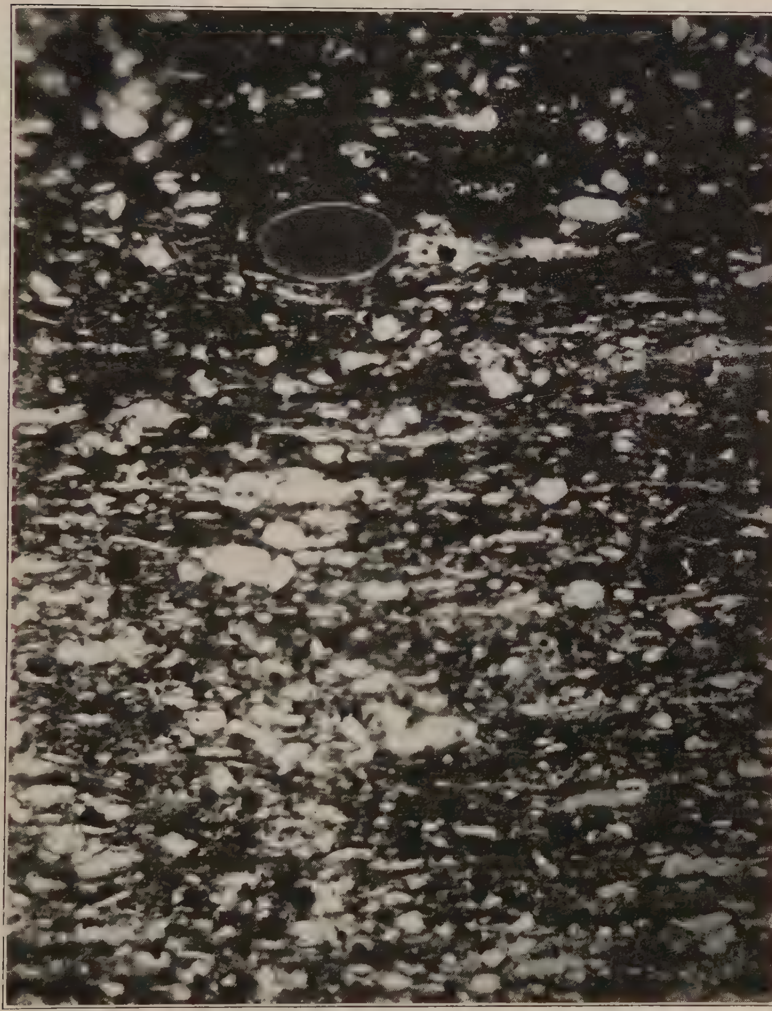

PLATE X.—Cross section of oil shale of the Devonian of Lincoln County, Kentucky (× 200), showing fragments of spores, microspores, pyrite particles and a large amount of mineral matter.

marks and other characters have been preserved well enough to ally them with the spores of *Pteridophytes* common in the Paleozoic deposits. This is the spore found and illustrated by Johnson and Thomas, and, as mentioned earlier, described and called by Dawson, *Sporangites Huronensis,* and later called by him *Proto-*

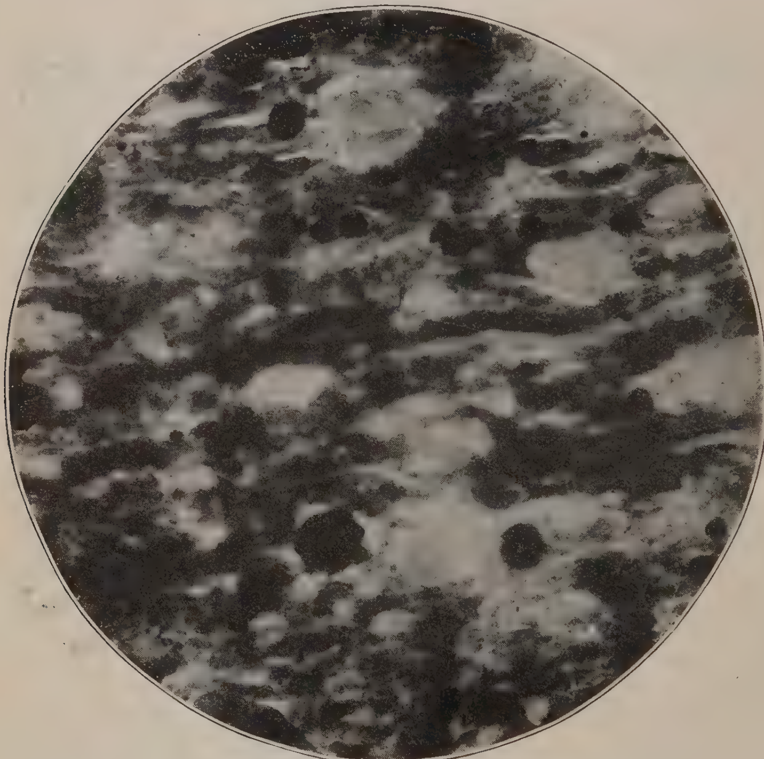

PLATE XI.—Cross section of oil shale of the Devonian of Lincoln County, Kentucky (× 1000), showing part of Plate X in detail. Notice the thinly laminated condition of the groundmass, also clay matter, quartz grains, and pyrite particles and dark colored organic matter.

salvinia Huronensis, as he believed them to be the spore-carps of an ancient Salvinia.

Much of the fragmentary spore matter is recognized as being from the same type of spores. Some of this matter, however, is so fragmentary and macerated that it can only be recognized as spore matter through its appearance and behavior towards reagents. Other spores are much larger and thin-walled as shown by the photographs, and probably represent a second type. Besides these large spores, a number of microspores—that is, spores much smaller in size—are found. The amount of spore matter furnished by this type so far as recognizable is but small. These spores are very poorly preserved, and nothing can be said concerning their structure, markings and shape, but it is probable

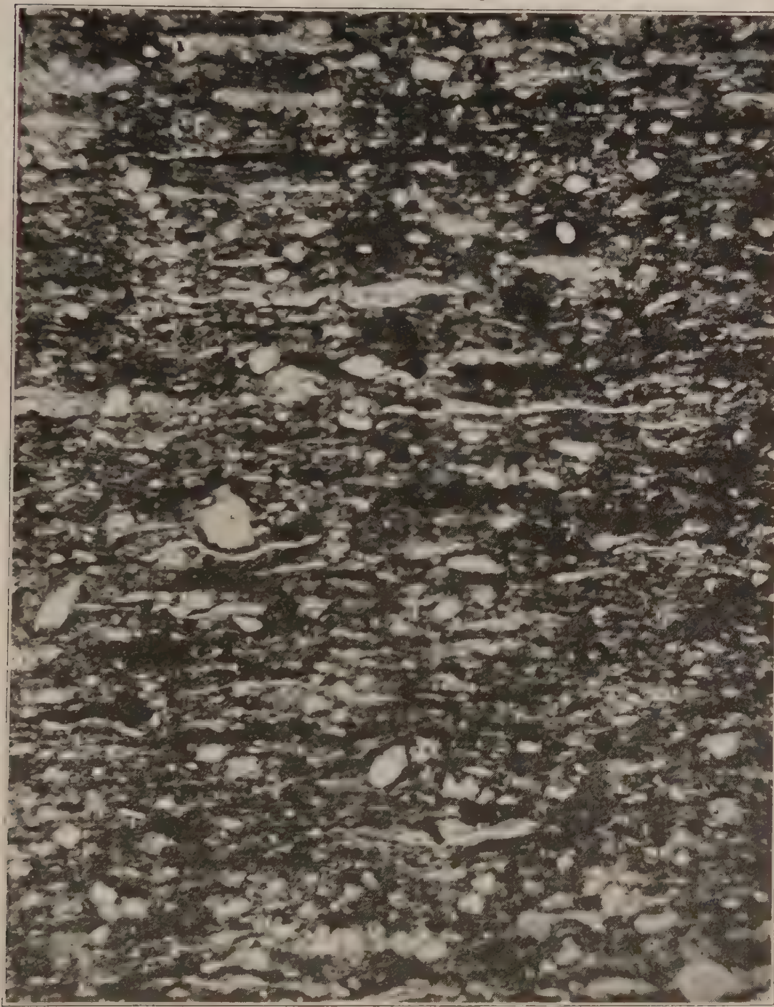

PLATE XII.—Cross section of oil shale of the Devonian of Rowan County, Kentucky (× 200). The groundmass is quite well resolved and represents the typical appearance of the groundmass of any section.

that a considerable amount of the general spore matter was contributed by this type. The thick-walled spore first found by Culver[10] in the shales of the Devonian of Illinois, has not been found in any of the samples examined from Kentucky.

[10] Thiessen, Reinhardt, Origin of certain oil shales, Econ. Geol., Vol. 16, 1921, pp. 289-300.

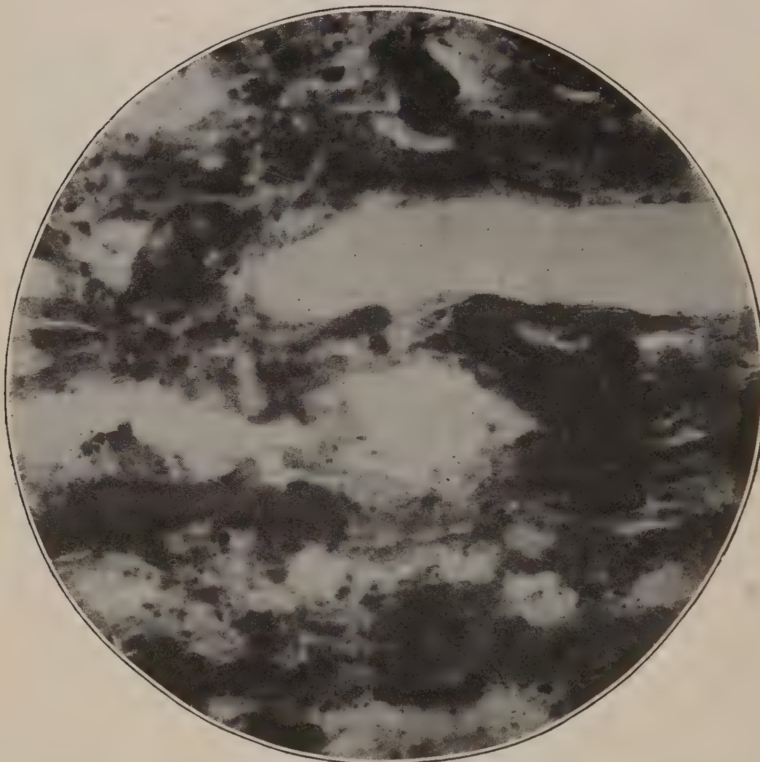

PLATE XIII.—Cross section of oil shale of the Devonian of Rowan County, Kentucky (× 1000), showing the groundmass in detail. Part of a larger spore and fragments of spores are included.

The Mineral Matter

As already stated, the mineral matter consists of clay matter, fine quartz particles, and finely disseminated pyrite. The larger proportion of the mineral matter consists of quartz and clay matter, while the pyrite particles, although considerable, constitute the smallest portion.

The clay matter, of course, constitutes the groundmass, and the embedding material for all the other constituents. This is so intimately associated and mixed with the organic matter that it can not be distingushed from it, even at the highest manification.

When the organic matter is burned out of a piece of the shale at a low temperature it remains in its original solid form

of considerable hardness, but is usually fissile and easily cleavable into thin sheets along its bedding plane. It is of reddish color due to the partly oxidized iron compounds, both of the pyrite and clay matter.

The mineral matter does not suffer any material change, and is in much more favorable condition for examination. It is compact enough to permit of grinding into thin sections to permit of microscopic and petrographic examinations. (Plates XXIX, XXX, XXXI, XXXII, XXXIII, XXXIV, XXXV.)

In such a section, the larger proportion appears colorless. By a careful examination, and especially with the petragraphic microscope, a large part of the colorless matter is shown to consist of vrystalline matter, almost all of which is quartz. The quartz consist of particles of all sizes from the smallest visible to that of 20 to 30 microns in diameter. Particles of larger diameter are exceedingly rare. Occasionally in certain parts of the sections, aggregates of particles of considerable sizes are to be found. These are usually in sheets or lenticular masses. The quartz is thus seen to occur in relatively small grains. Some of the particles are shown in the photographs (Plates XXXI, XXXII, XXXIV), but they are best shown when seen between crossed nicol prisms. The remainder of the colorless matter is clay matter. Most of it is so finely divided that its particles can only be seen with an ultra-condenser, but some of the grains of kaolin are large enough to be seen at a high magnification by ordinary illumination (Plates XXXI, XXXII, XXXV), their characteristic form may then be recognized.

Among the colorless matter are lodged, beside the opaque pyrite particles, a considerable number of particles of various forms and shades of coloration between light transparent yellow to a dark opaque or reddish-brown. Under the microscope, with ordinary illumination by transmitted light, they appear as transparent to translucent and opaque homogeneous masses. When viewed with an ultra-condenser, most of them are shown to be composed of ultra particles, thus shown to be clay matter; others have a homogeneous or crystalline central part, usually a prismitic shape surrounded by matter that is obviously clay matter. Some have an opaque spherical nucleus, obviously of pyrite, surrounded by clay matter; others again have the clay mat-

PLATE XIV.—Cross section of oil shale of the Devonian of Bath County, Kentucky (× 200), showing a number of thin walled spores and fragments of spores in a groundmass partly resolved.

ter in the center surrounded by a pyrite shell. Other similar combinations may be noted. The large prismitic particles shown in Plate XXXV consist of a plate of Crystalline matter, surrounded or fringed by a dark-brown clay matter. Above and below it, toward the central part of the figure, are pyrite glob-

PLATE XV.—Cross section of oil shale of the Devonian of Jefferson County, Kentucky (× 200). Not much spore matter is apparent, nevertheless most of the organic matter is ceric matter.

ules. The minute lumps of clay matter vary greatly in size and form; and may be distinguished from the pyrite particles through their indefinite outline, the pyrite particles having sharp and distinct outline. (Plates XXXI, XXXII, XXXV.) Besides these, there are numerous very small red particles—easily visible with an oil-immersion lens and just visible with

16-millimeter lens—of uniform size and found in groups of a few to several hundred. These are very similar in appearance to those of iron oxide.

A noteworthy fact is that in burning out the larger particles of organic matters, such as spores and particles of humic matter, no holes were left in their places, the holes being still occupied by a very fine structure of mineral matter, as shown by Plates XXXI and XXXII.

The Pyrite

All of the samples contain iron pyrite in a very finely disseminated state, and distributed uniformly through the shales, shown well in Plates IX, XI and XXIII. The majority of the particles are distributed singly, but here and there two or more are grouped into irregular secondary particles, and occasionally a large number are arranged together to form more or less lenticular masses. The shape of the individual particles is generally roughly spherical, but cubical and hexagonal forms are common, and occasionally irregular or rough forms are also seen.

In size, they range from those barely visible, under the highest power, to as large as 20 to 30 microns, rarely larger, except as aggregates.

The total amount of the pyrite, of course, varies from section to section and from sample to sample, but in general, within but small limits. The general appearance of the particles is similar to those in coal, but are more uniformly distributed and on the whole more numerous.

In the ash sections, the pyrite particles stand out sharply from the other constituents. (Plates XXXIV, XXXV.)

The Formation of the Deposit

Geologists tell us that the Devonian deposits covering the eastern and central part of North America were laid down under relatively quiet conditions in an extensively shallow basin called the Appalachian Trough. The sea is supposed to have encroached on and retreated from this area a number of times, indicating that the area consisted on the whole of an extensive flat level country, in elevation always relatively close to sea-level over a long period of time.

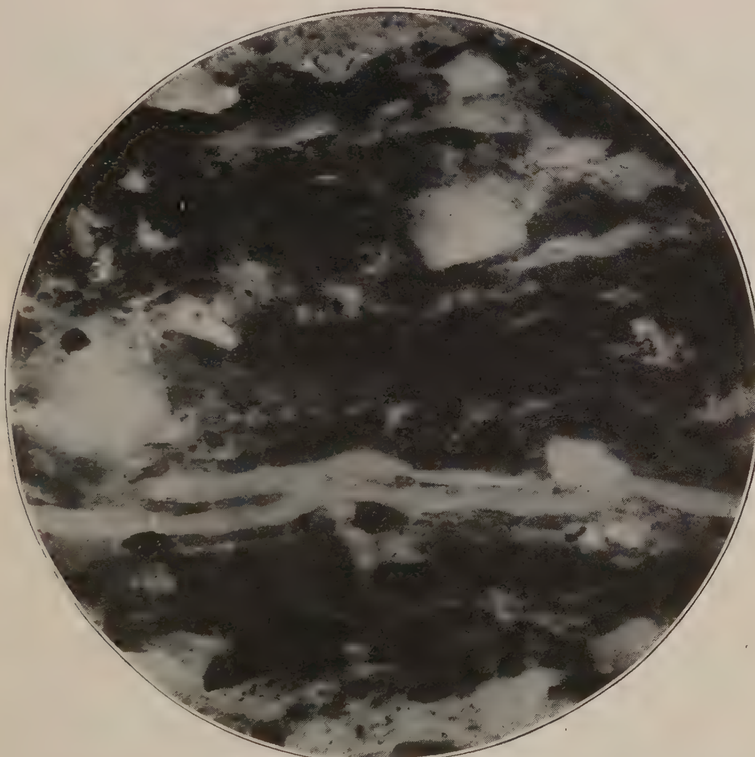

PLATE XVI.—Cross section of oil shale of the Devonian of Jefferson County, Kentucky (× 1000), showing the groundmass in detail. Fragments of larger spores, microspores are shown. Notice the finely laminated but distorted condition of much of the groundmass.

During, and at the close of the Middle Devonian period, the sea had again receded, and the territory now occupied by Illinois, Michigan, Indiana, Ohio, Kentucky, Tennessee, Alabama, etc., formed then a vast shallow plain, very poorly drained. It is supposed that rivers drained into this area from the south. southwest and the west, and spread muds laden with plant debris over the region, giving rise to the Devonian black shales of that territory. There must have been a period, or a succession of periods, when the whole area, or successive parts of this area, were covered with vast swamps or marshes. Those swamps can not have been of the same nature as that of the dismal swamp or swamps similar to those that gave rise to the Pittsburgh coal bed, for then extensive coal beds would be found where now we

PLATE XVII.—Cross section of oil shale of the Devonian of Bullitt County, Kentucky (× 200). Spores, quartz grains and aggregates of quartz grains and pyrite particles are well shown.

have black shales. The whole area must have consisted of a succession of large shallow lakes. These waters must have thrived with hydrophytes very similar in habit to those of today. Some probably anchored at the bottom, others floating in an entangled mass among these and holding on them for support. As to the

PLATE XVIII.—Cross section of oil shale of the Devonian of Powell County, Kentucky (× 200) giving a typical appearance of the groundmass of any section at a higher magnification.

kind of plants, we can make but a guess; they probably were *Pteridophytes,* related to the *Lepidodendrons,* similar in habit to our water ferns like *Azolla, Marsilia,* or *Salvinia* of today. Here and there conditions prevailed in which types like the *Cordaites, Medullosae,* and *Lepidodendrons* could exist sparingly.

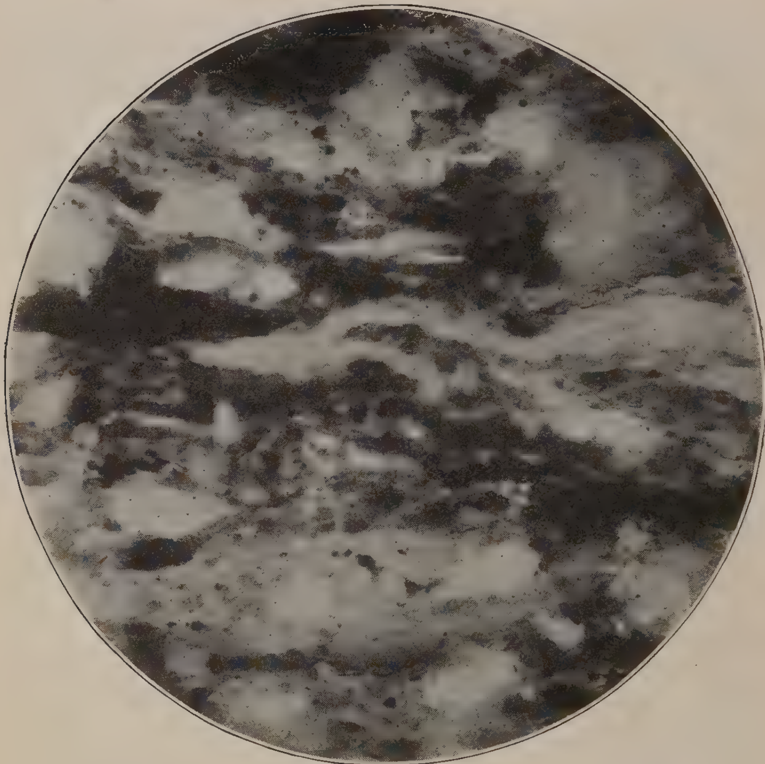

PLATE XIX.—Cross section of oil shale of the Devonian of Powell County, Kentucky (× 1000), giving details of the groundmass of section shown in Plate XVIII. Fragmentary and macerated spore matter is distinguishable from quartz clay and other matter.

As to the mode of decay and decomposition of plants of a mesophytic habitat, and the formation of deposits of their remains, we are better informed and no guesses have to be made. Such conditions are being repeated in many places today.

Hydrophytic plants—that is, plants living in water totally submerged, anchored at the bottom, or floating—are, as a rule herbaceous, and of a very loose, spongy structure. At their death they decay and disintegrate very readily, and only those products and organs of the plants that are able to resist the putrefying agents remain and sink to the bottom. It is well known that spore coats, cuticles, pollens, waxy coverings, waxy and oily cell contents, as well as a host of other plant products, are not attacked by bacteria and fungi nor oxidized in the air.

PLATE XX.—Cross section of oil shale of the Devonian of Lewis County, Kentucky (× 200). This section contains much dark, charred matter, otherwise similar to other samples; but low in organic matter.

At death and decay of the plant, these remain—some entire, some in fragment, and some as an ooze—and together with the mineral matter of the plant itself, mineral matter wind blown, and mineral matter drifted of floated in, form a deposit that is largely ceric.

PLATE XXI.—Cross section of oil shale of the Devonian of Rockcastle County, Kentucky (× 200). This is one of the leanest of the samples; the low percentage of organic matter and high percentage of mineral matter is evident.

When a deposit has been formed under these conditions, it is found to consist exactly of these constituents, which correspond precisely with those that compose oil shales and cannel coals. They consist chiefly with what has been termed the ceric components of plants.

Such deposits may or may not have foreign silts added to them through inflowing waters or through the air. The silt washed or blown in would not change the character of the organic material. The organic matter of cannel coals, cannel slates, and oil shales of a certain type, to which the Devonian oil shales belong, is always similar in character, and it is only the mineral matter that differs in them.

Summary

The Devonian oil shales of Kentucky are of the spore type of deposits. The Paleozoic deposits, to which belong the cannel coals, boghead coals, torbanites, and oil shales, can be divided into four types, namely, the humic, spore, boghead and ceric.

They are composed of essentially three components, namely, clay, organic matter and pyrite. The clay constitutes the ground or medium in which the other constituents are embedded.

The organic matter consists mainly of spores, cuticular and other ceric matter, and very little humic matter. The spore matter predominates. The pyrite is distributed in the form of very small more or less spherical granules. The clay is composed of such matter as clays are ordinarily composed, but with a high content of colloidal matter.

The amount of spore matter in general is proportional to the relative amount of organic matter as observed under the microscope, and also proportional to yield of distillates. The relative amount of spore matter, therefore, is a fairly good indication as to the richness of the shale.

The characters of the spores are but poorly preserved, but there is no doubt that they belong to the *Peridophytes* of the Paleozoic times.

The samples represent the shale from widely separated parts of Kentucky, but are remarkably similar except in the relative amount of organic matter.

Microscopic Laboratory,
Chemical Division,
Pittsburgh Experiment Station,
U. S. Bureau of Mines,

May, 1925.

PLATE XXII.—Cross section of oil shale of the Devonian of Marion County, Kentucky (× 200). This is also from one of the leanest samples of the series, containing a high percentage of clay and pyrites.

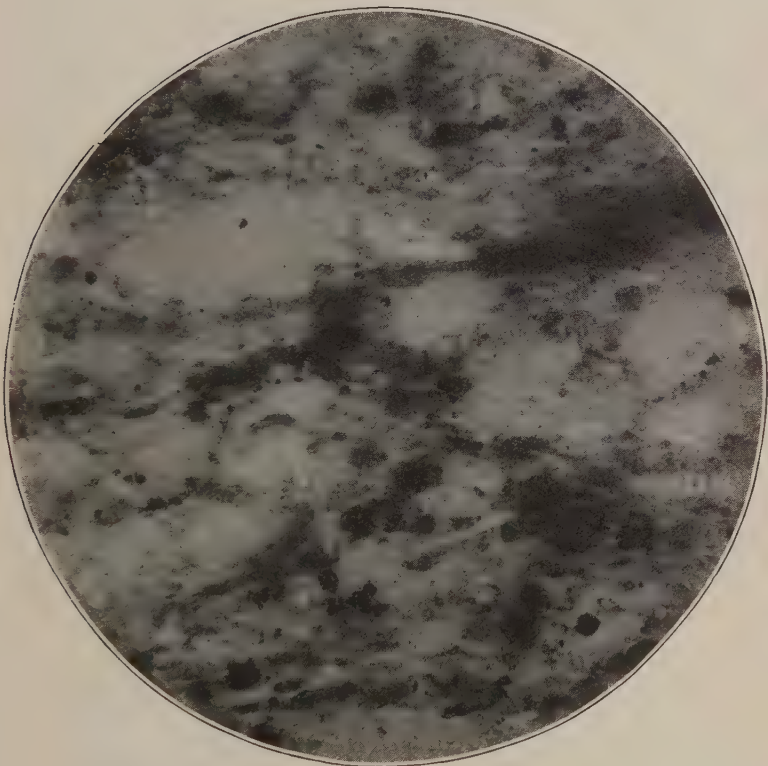

PLATE XXIII.—Cross section of oil shale of the Devonian of Marion County, Kentucky (× 1000), showing part of section shown in Plate XXII in detail.

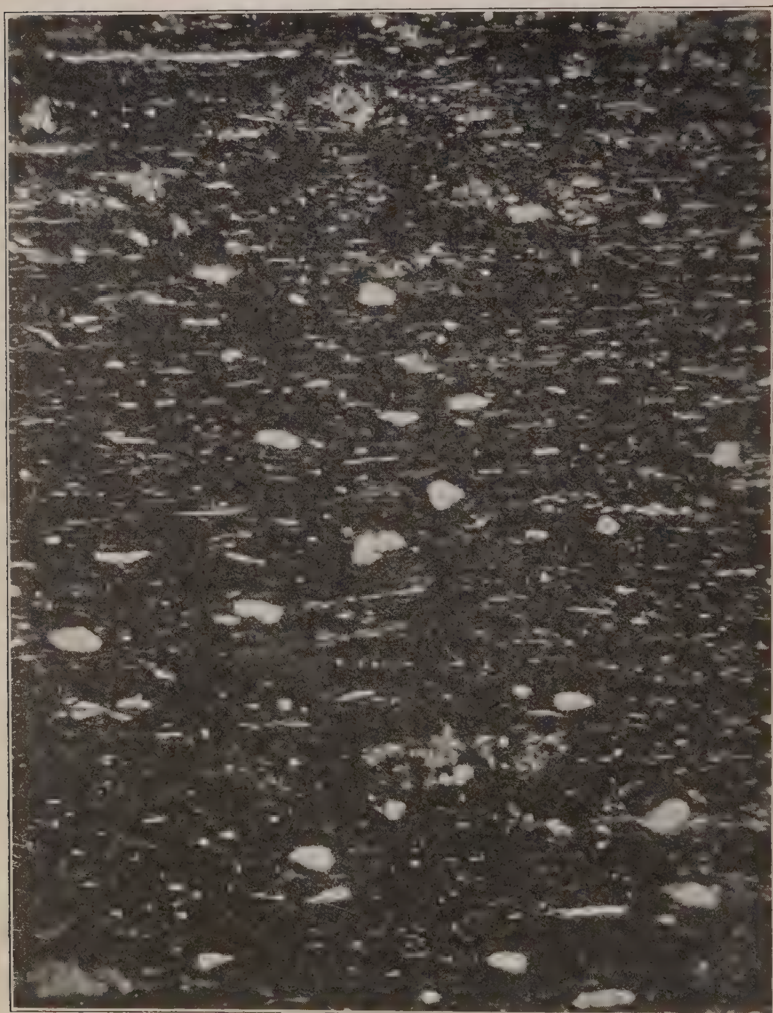

PLATE XXIV.—Cross section of oil shale or cannel slate of Pottsville age (Pennsylvanian) from Morgan County, near Wrigley, Kentucky ($\times$ 200). This is a spore shale from another horizon, not Devonian, shown for comparison. This shale is richer in organic matter than shown by any of the samples of the Devonian shales, having a combustile matter of nearly 70 per cent. The relative amount of spore matter is large. It contains relatively large quartz grains as shown by the white spots.

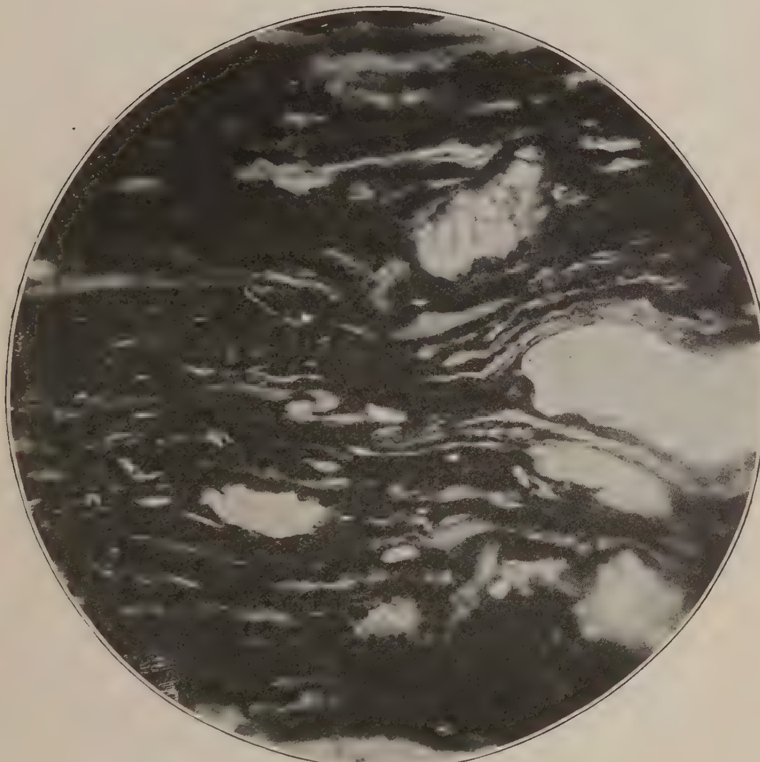

PLATE XXV.—Cross section of oil shale or cannel slate of Pottsville age (Pennsylvanian) from Morgan County, near Wrigley, Kentucky (× 1000), showing part of the section shown in Plate XXIV in detail. The horizontal white bands represent spore matter. The larger more or less regular areas represent quartz; some of these show the granular composite structure. The dark bands and more or less irregular dark areas represent macerated brown organic matter mixed with clay.

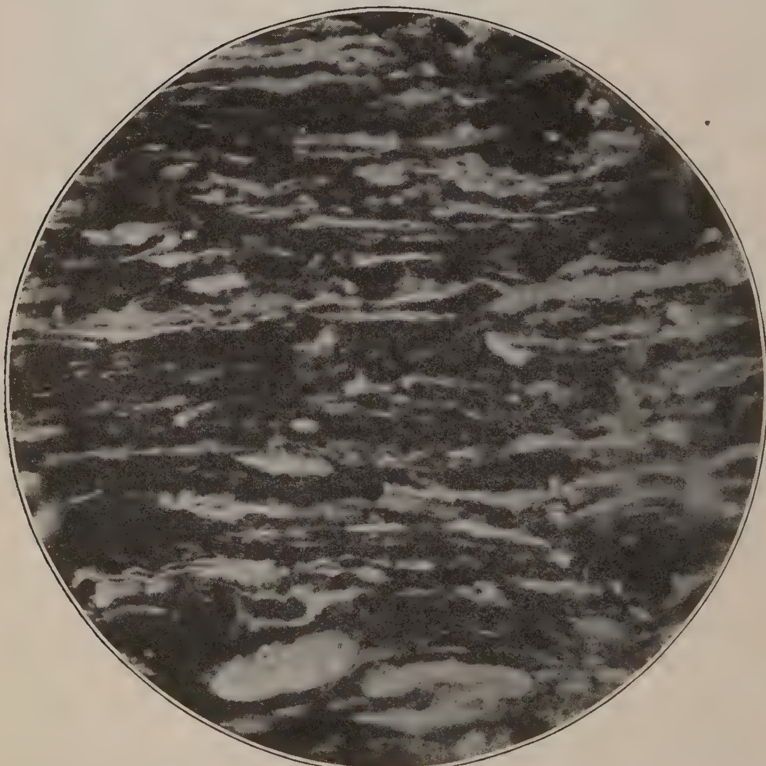

PLATE XXVI.—Another cross section of oil shale of Pottsville age (Pennsylvanian) from Morgan County, near Wrigley, Kentucky (× 1000), showing the composition of the shale in detail. The lighter parts represent largely spores, fragments of spores and cuticular matter. The darker parts represent macerated organic matter mixed with clay. The solid black parts represent pyrite particles; only little quartz is represented. The shale is a typical spore shale.

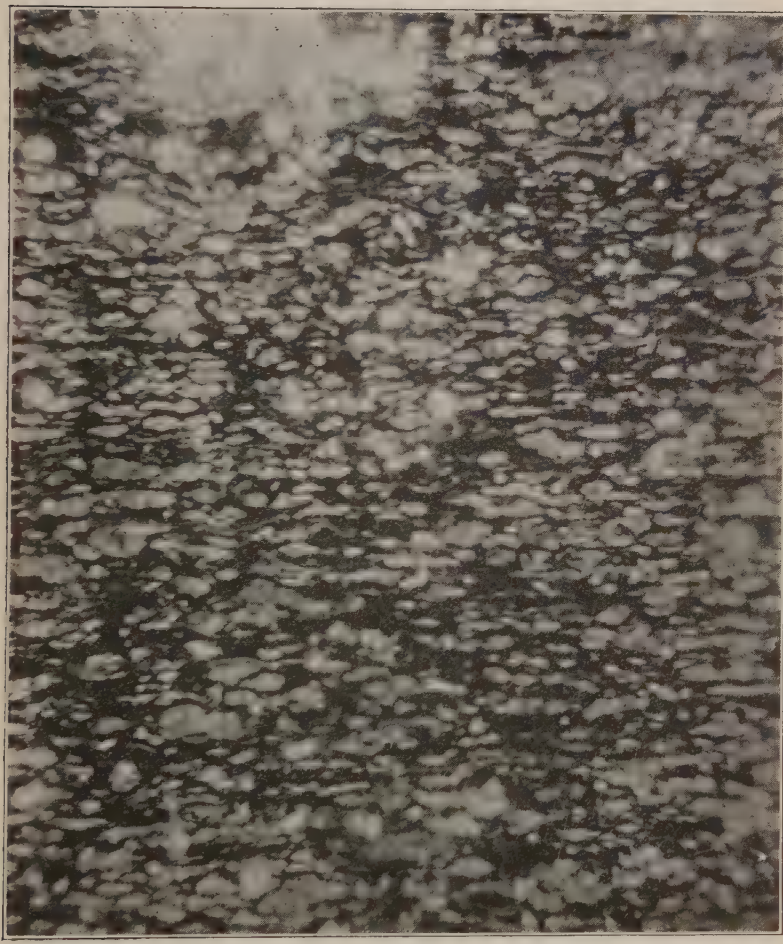

PLATE XXVII.—Cross section of the Kiskiminetas cannel coal from the Allegheny Formation, between Upper and Lower Freeport coals (× 200.) This represents the type of the deposits probably composed very largely of oil algae, shown for comparison with a spore shale.

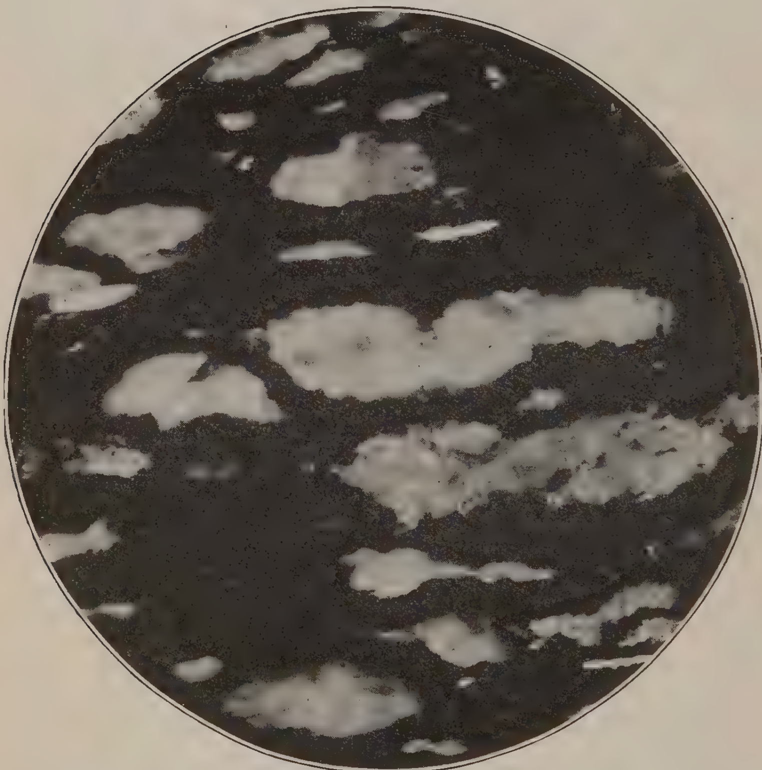

PLATE XXVIII.—Cross section of the Kiskiminetas cannel coal from the Allegheny Formation between the Upper and the Lower Freeport coals (× 1000), showing the main constituent in detail.

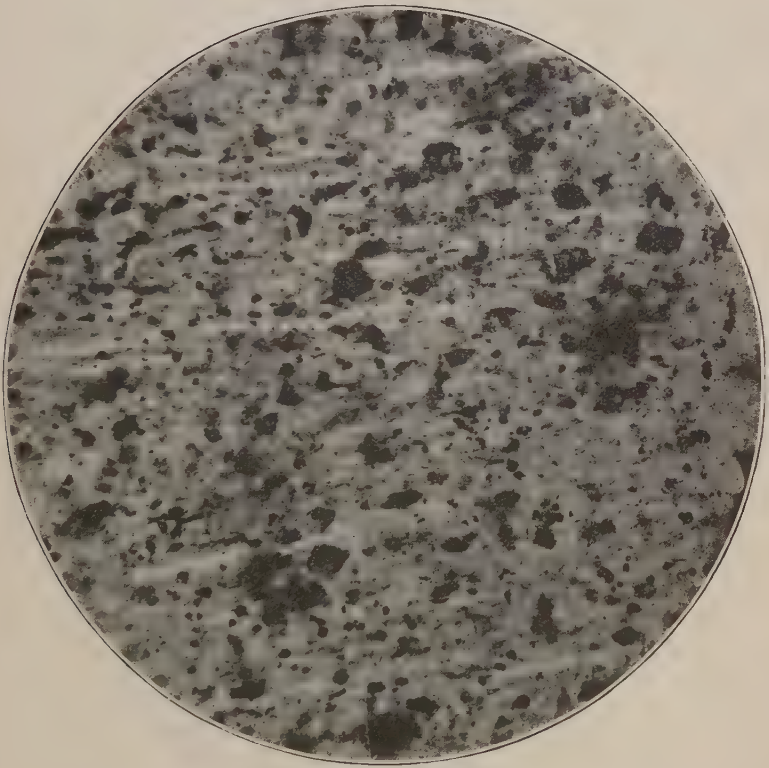

PLATE XXIX.—Oil shale from the Devonian of Powell County, Kentucky, organic matter removed by burning ($\times 200$). The black spots represent oxidized clay matter of a red color and pyrite particles. The clays may be recognized in a general way in that they have an irregular and indefinite outline, whereas the pyrite particles are as a rule represented by smaller, clean cut black dots. The lighter areas represent places formerly occupied by spores, in which a fine structure of mineral matter remained.

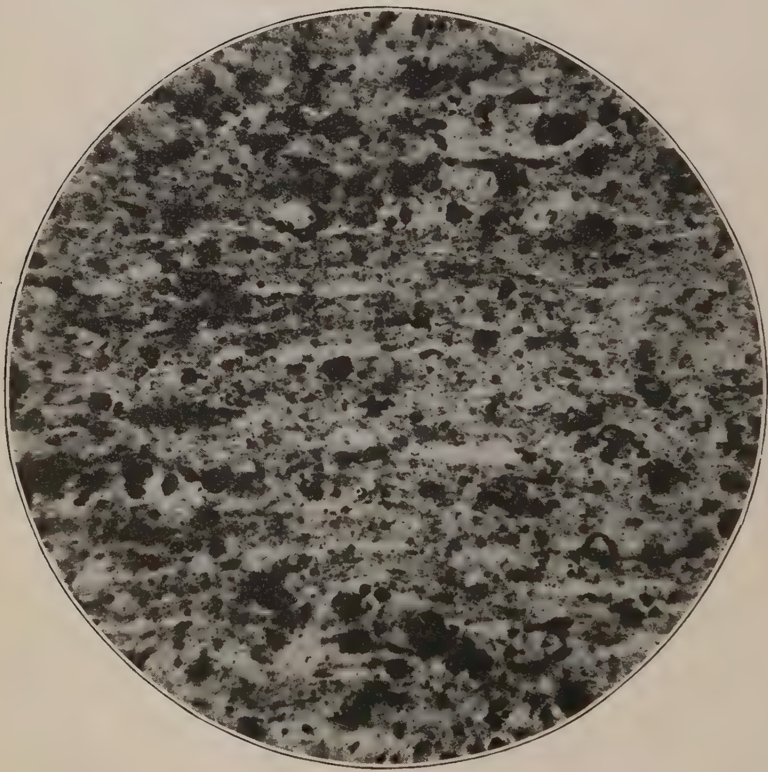

PLATE XXX.—Oil shale from the Devonian, Boyle County, Kentucky, from which the organic matter was removed. The black again represents oxidized red colored clay and pyrite particles. The former places of spore matter are clearly shown by the white banding.

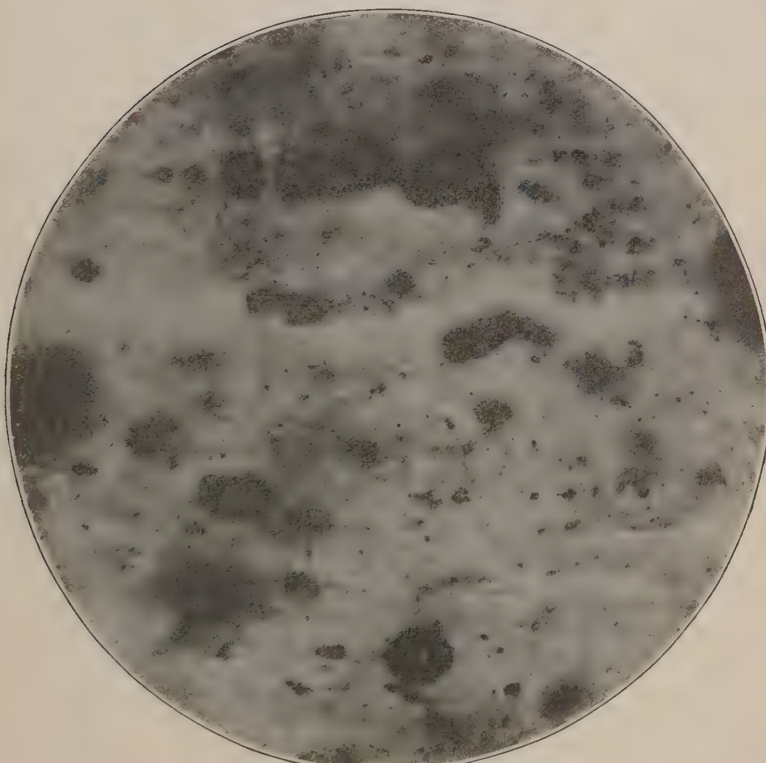

PLATE XXXI.—Oil shale from the Devonian of Kentucky from which the organic matter has been removed by burning (× 1000), showing part of Plate XXX in detail. The pyrite particles are represented by the smaller, more sharply outlined black spots, while the clay is represented by less definitely outlined black spots. The former position of spores is markd by lighter bands. Kaolin particles are clearly seen.

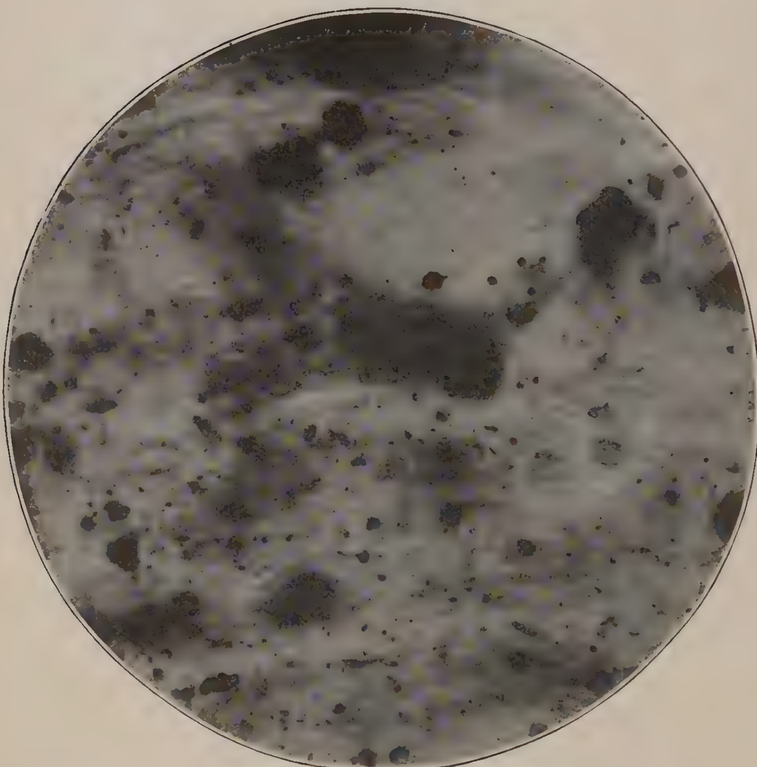

PLATE XXXII.—Oil shale from the Devonian of Kentucky from which the organic matter has been removed by burning (× 1000), showing part of Plate XXX in detail. The pyrite particles are represented by the smaller, more sharply outlined black spots, while the clay is represented by less definitely outlined black spots. The former position of spores is marked by lighter bands. Kaolin particles are clearly seen.

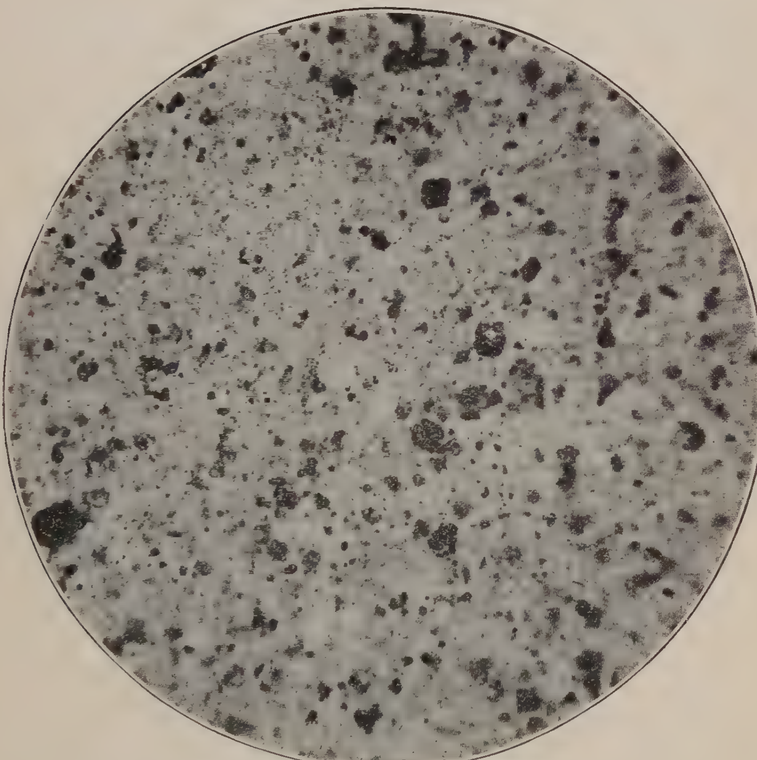

PLATE XXXIII.—Horizontal section of oil shale from the Devonian of Kentucky (×200), with the organic matter burned out.

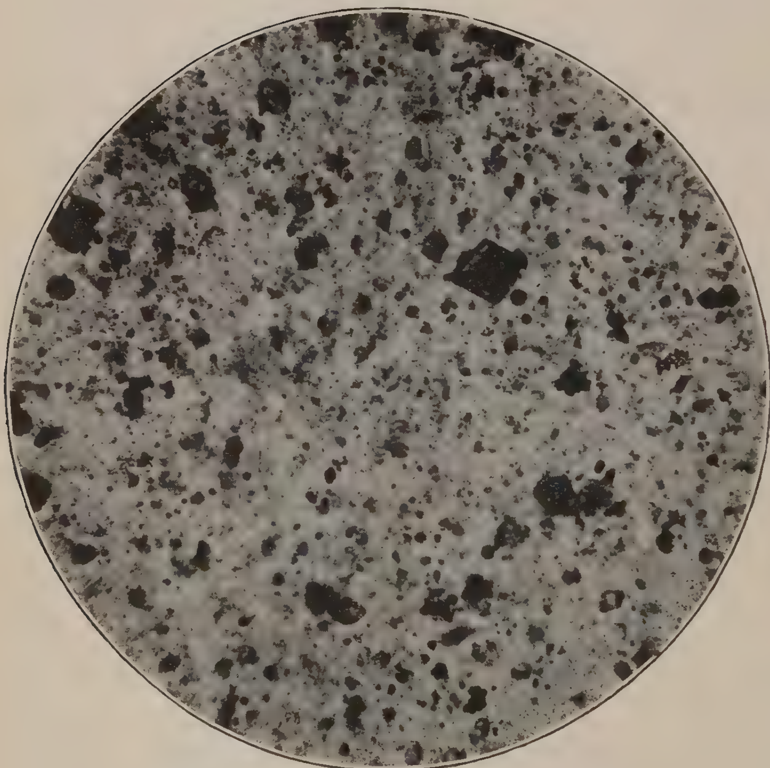

PLATE XXXIV.—Horizontal section of oil shale from the Devonian of Kentucky (× 200), with the organic matter burned out.

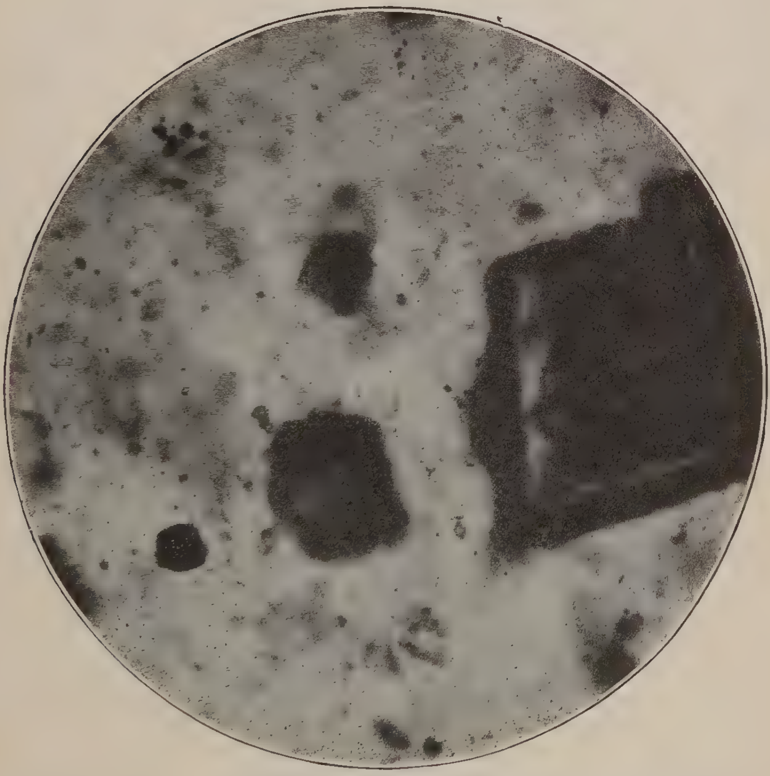

PLATE XXXV.—Horizontal section of oil shale from the Devonian of Kentucky, showing part of Plate XXXIV in detail (× 1000). The large figure represents a crystal surrounded by red clay and superimposed by pyrite particles and clay.

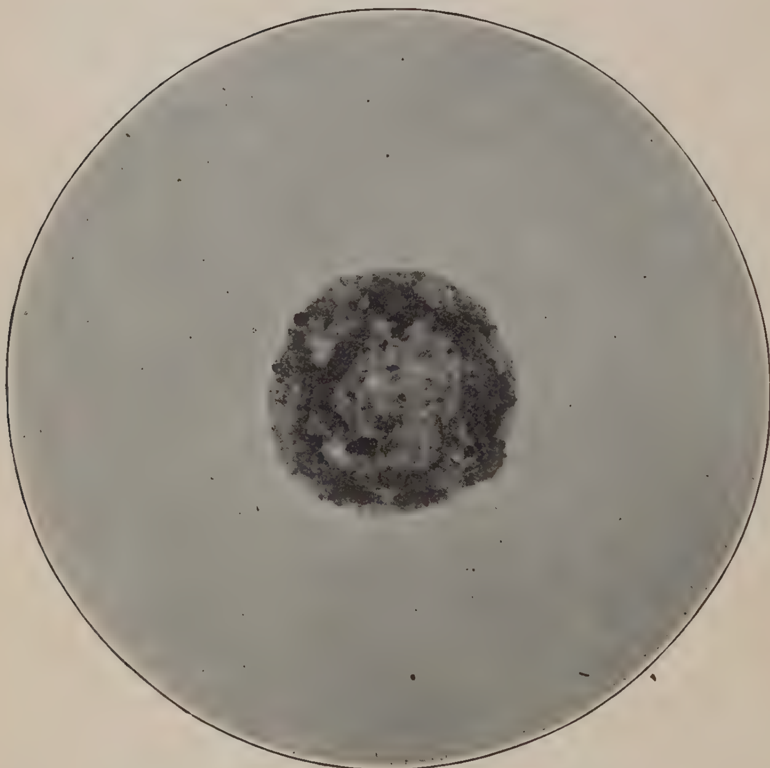

PLATE XXXVI.—The predominant spore isolated from the oil shale of the Devonian from Kentucky, magnified 200 diameters.

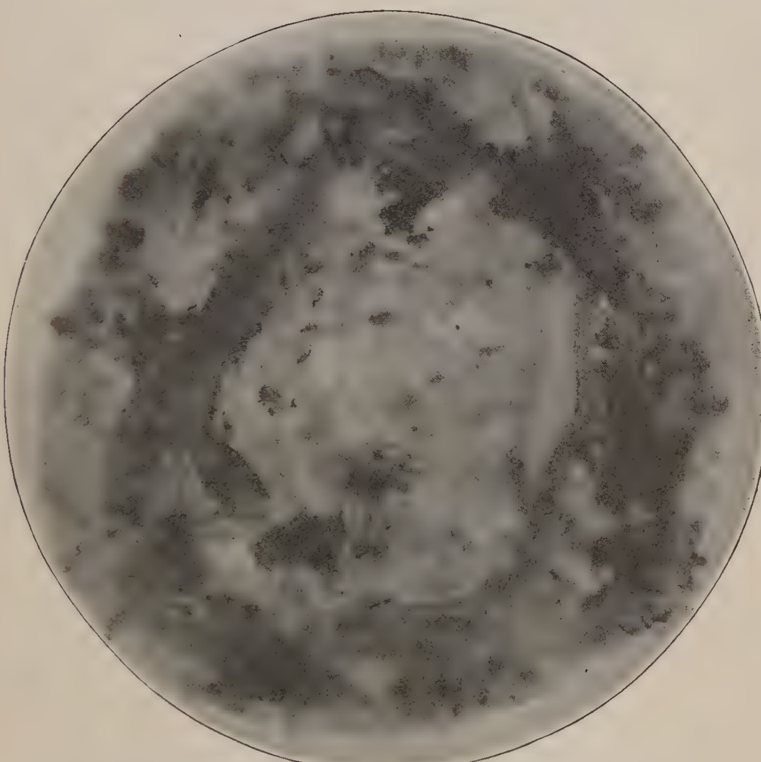

PLATE XXXVII.—The same spore magnified 650 diameters.

II.

THE PRECIOUS METAL CONTENT OF THE BLACK DEVONIAN SHALES OF KENTUCKY

By Charles Stevens Crouse

Oil Shale Technologist

Whenever the demand for a great natural resource comes dangerously close to the prospective supply a great deal of interest is manifested in any possible method of overcoming the threatened shortage. This interest is taken first by those in most intimate contact with the particular industry concerned and secondly, and more tardily, by the public at large, that public which is most concerned but hardest to arouse. So it has been with oil and the greatest potential source of oil, oil shale.

However, in the past two or three years considerable publicity has been given to the recovery of oil from the shales of the United States in general and also to the recovery of certain byproducts, the commercial importance of the latter oftentimes having been overstressed. Among these byproducts which, it is claimed, may be commercially recovered, especially from western shale, are the precious metals, gold and silver. In November of 1922, a paper by Thomas Varley was published by the United States Bureau of Mines on the presence of gold in oil shales and its possible recovery. This paper dealt entirely with western shales. A few months later the writer started an investigation in the mining laboratory at the University of Kentucky along much the same lines, but on Kentucky shales. This was done in order that there might be some authoritative data available to show exactly what precious metal values, if any, might be expected from the Kentucky oil shales.

Most of the samples chosen for analysis were those collected by the writer in the fall of 1920 and analyzed, for oil, by him during that year, the data obtained at that time appearing in "A Preliminary Report on the Oil Shales of Kentucky"[1] by W. R. Jillson, State Geologist. A few samples have been added to these in order to make the series more complete.

[1] Kentucky Geological Survey, Series VI, Vol. II, Paper No. 1. 1921.

In starting the investigation two different methods of procedure presented themselves: the shale could be assayed raw, that is, before any volatiles were driven off and just as it came from the deposit, or it could be assayed after having been subjected to a roast in order to drive off these volatiles in which case it would be in much the same condition as though it had been passed through a commercial retort and the oil content removed. If this latter method were used, two distinct ways of proceeding were offered; the shale might be roasted at a high temperature or it might be roasted at a low temperature. If no appreciable difference in results were shown the assaying of the roasted ore would be preferable as it would more nearly meet the conditions of actual commercial operation. Accordingly three samples of different shale were taken, crushed, quartered, recrushed and sampled. Two samples of each of these were then assayed raw, two after roasting at a high temperature and two after roasting at a low temperature, thus giving two samples of three different shales under each heading. After figuring the results on the raw shale on the basis of roasted shale no appreciable difference was found in the result from any one of the three methods used, so it was assumed that the method of roasting did not affect the precious metals in the shale. These results were also borne out by the findings of the Bureau of Mines on western shales as the paper, by Mr. Varley, mentioned before, states, "that no special precautions are necessary in assaying the shale for gold, and that any direct assay by a reliable method will give the true gold content of the original material," and again, "that there is no loss by volitilization in the samples either during distillation of the oil or during further heating and decarbonization, which is greater in amount than the limiting accuracy of a gold assay at its best."

Such being the case it was decided to roast all samples uniformly so as to remove all volatiles, some of the fixed carbon and some of the sulphur in order to put the shale as nearly as possible in the condition it would normally be in after commercial destructive distillation. The samples were therefore all roasted and assayed on the basis of spent shale. This means that all precious metal values shown are in ounces per ton of roasted or "spent" shale and not in ounces per ton of raw shale, which also

means that the results obtained are higher than they would have been had the raw shale been taken as the original material because the shale shows a loss of around 20% in weight on roasting.

The next thing to be determined was the charge which would give the best results in the actual assaying so that all samples could be treated with this charge, thus giving comparable results. After a sufficiently large number of trials the following charge was found to give an excellent fusion in the crucible, a good lead button with a clean separation of slag and lead, and a good cupellation and was, accordingly, adopted as the standard: 60 grams of bicarbonate of soda, 10 grams of borax, 2.5 grams of argols, 40 grams of litharge, 1 assay ton of ore and a salt cover. The fusions were all run in the same gasoline crucible furnace at a uniform temperature and the cupellations in the same gasoline muffle furnace, also at a uniform temperature. In addition check assays were made on all the reagents used in order to determine whether or not they might contain any values. These assays showing no results the fluxes used were considered to be gold and silver free. Therefore, as particular care was taken in every step of the assay to prevent "salting" in any way, all values shown may be taken at their face value and represent actual gold and silver in the shale.

The following data shows the locational records of the samples assayed, the amounts of gold and silver found, and their combined value per ton of roasted shale using values of $20.66 per ounce for gold and 60 cents per ounce for silver.

Bath County

Location: About a half mile from Salt Lick on the Caney road. Sample taken on a hill about twenty-five feet above a clay seam which lies near the bottom of the deposit.

Results: 0.21 oz. silver, 0.01 oz. gold, combined value 34 cents per ton.

Boyle County

Location: In the western edge of Junction City near the building of the Kraemer Oil Company. Sample taken from a quarry on the north side of the road.

Results: 0.015 oz. silver, trace gold, combined value negligible.

Bullitt County

Location: Just out of Shepherdsville on the Louisville-Shepherdsville road at the gap in the knobs where the highway crosses the L. & N. R. R. on a high bridge. Sample taken from the railroad cut at the above location.

Results: 0.22 oz. silver, 0.01 oz. gold, combined value 34 cents per ton.

Casey County

Location: About a quarter of a mile west of the gap in the knobs on the Hustonville-Bradfordsville pike. Sample taken from a small road quarry on the right of the road on Mrs. Power's farm.

Results: 0.085 oz. silver, 0.015 oz. gold, combined value 36 cents per ton.

Clark County

Location: About half a mile east of Indian Fields on the Winchester-Clay City road. Sample taken from an old road quarry situated just over the crest of a hill from a school house.

Results: 0.03 oz. silver, 0.01 oz. gold, combined value 23 cents per ton.

Cumberland County

Location: From an outcrop on the Cumberland river.

Results: 0.05 oz. silver, 0.02 oz. gold, combined value 44 cents per ton.

Elliott County

Location: From the first 100 feet of the basal Pottsville exposed in the branch at the head of Corn Hollow on the Charles LeMaster farm on the headwaters of Big Sinking Creek. This bituminous shale was collected from the Lower Pottsville formation on the headwaters of Big Sinking Creek in Elliott county, Ky., by W. R. Jillson, September, 1920. It is not the black or Chattanooga (Devonian) shale.

Results: 0.115 oz. silver, 0.015 oz. gold, combined value 38 cents per ton.

Estill County

Location: About two miles from Irvine on the opposite side of the Kentucky river as the road goes to Richmond. This is known as the Sand Hill district.

Results: Trace silver, trace gold, combined value negligible.

Fleming County

Location: Taken from near the top of the first mountain east of Ringo's mill. Sample came from near the top of the deposit.

Results: 0.03 oz. silver, trace gold, combined value 2 cents per ton.

Garrard County

Location: From the bottom of Copper Creek which is the Rockcastle-Garrard County line. Sample taken from the point where the Copper Creek road crosses the creek.

Results: 0.41 oz. silver, 0.01 oz. gold, combined value 46 cents per ton.

Jefferson County

Location: About one mile south of Twin Oaks Park on the Ash Bottom road. Sample taken from freshly blasted material from a well being dug on the L. & N. R. R. property at about 100 feet to the right of the road.

Results: 0.02 oz. silver, 0.01 oz. gold, combined value 22 cents per ton.

Lee County

Location: Sample taken from a drill hole one-half mile above the mouth of Cave Fork of Big Sinking Creek. The sample was taken when the drill was 130 feet from the top of the shale and 20 feet from the bottom. There is no outcrop shale in Lee County.

Results: 0.01 oz. silver, 0.00 oz. gold, combined value negligible.

Lewis County

Location: About a mile and a half from Vanceburg on the Maysville road. Sample taken from a cut alongside the road.

Results: 0.015 oz. silver, 0.015 oz. gold, combined value 32 cents per ton.

Lincoln County

Location: About one mile from Milidgeville on the Black pike. Sample taken from the ditch alongside the road.

Results: 0.04 oz. silver, trace gold, combined value 3 cents per ton.

Madison County

Location: In Berea. Sample taken from blasted material from the cellar of the house of the president of Berea College.

Results: 0.08 oz. silver, 0.01 oz. gold, combined value 26 cents per ton.

Marion County

Location: About half a mile east of Lebanon on the Lebanon-Danville pike. Sample taken from a quarry in Ryder's cemetery.

Results: 0.025 oz. silver, 0.005 oz. gold, combined value 12 cents per ton.

Montgomery County

Location: About eight miles east of Mt. Sterling on the Old Town road. Sample taken on the property of the Central Shale Oil Corporation.

Results: 0.025 oz. silver, 0.015 oz. gold, combined value 32 cents per ton.

Nelson County

Location: About one mile from Boston on the Boston-Bardstown road. Sample taken from a quarry on top of a hill.

Results: 0.225 oz. silver, 0.005 oz. gold, combined value 24 cents per ton.

Powell County

Location: About one mile east of Clay City. Sample taken from the property of the Devon Oil Shale Products Company.

Results: 0.04 oz. silver, 0.01 oz. gold, combined value 23 cents per ton.

Rockcastle County

Location: On Boone Highway at Gum Sulphur. Sample taken from a cut alongside the road on the south side of Gum Sulphur Creek.

Results: 0.015 oz. silver, trace gold, combined value negligible.

Rowan County

Location: At the quarry of the Rowan County Freestone Company. Sample taken from the top of the deposit just below the soapstone.

Results: 0.055 oz. silver, 0.015 oz. gold, combined value 34 cents per ton.

Taylor County

Location: Outcrop in Robinson's Creek near Mansville, Taylor County.

Results: 0.165 oz. silver, 0.015 oz. gold, combined value 41 cents per ton.

The above samples were taken from various portions of the shale deposit from top to bottom, no attempt being made to locate them accurately in this respect. Therefore, in order to determine if the position of the sample, vertically, in the deposit, made any appreciable difference in the values obtained, three separate series of samples from different locations in the shale district were taken and assayed with the following results. It may also be said that none of the following samples duplicate any of those given above.

SERIES NUMBER ONE

Top of deposit: 0.00 silver, 0.00 gold.
10 feet from top: traces silver, traces gold.
40 feet from top: 0.04 oz. silver and gold.

SERIES NUMBER TWO.

40 feet from top of deposit: 0.04 oz. silver and gold.
50 feet from top of deposit: traces silver and gold.

SERIES NUMBER THREE

Location	Silver in oz	Gold in oz.	Combined value
Top of deposit	0.25	0.000	16 cents per ton
6 feet from top	0.39	0.000	23 cents per ton
11 feet from top	0.24	0.020	56 cents per ton
22 feet from top	0.22	0.010	34 cents per ton
26 feet from top	0.15	0.010	30 cents per ton
29 feet from top	0.10	traces	6 cents per ton
34 feet from top	0.12	traces	7 cents per ton
40 feet from top	0.08	0.005	15 cents per ton
Average	0.19	0.006	24 cents per ton

In the following table are assembled the oil and precious metal values of the samples tested:

County	Crude oil in gallon short ton of shale	Silver in oz. per ton of roasted shale	Gold in oz. per ton of roasted shale
Bath	11.25	0.210	0.010
Boyle	11.00	0.015	trace
Bullitt	5.00	0.220	0.010
Casey	18.00	0.085	0.015
Clark	11.00	0.030	0.010
Cumberland	——	0.050	0.020
Elliott	17.25	0.115	0.015
Estill	22.00	trace	trace
Fleming	21.50	0.030	trace
Garrard	21.00	0.410	0.010
Jefferson	15.50	0.020	0.010
Lee	5.00	0.010	0.000
Lewis	10.25	0.015	0.015
Lincoln	15.50	0.040	trace
Madison	18.50	0.080	0.010
Marion	16.00	0.025	0.005
Montgomery	19.00	0.025	0.015
Nelson	19.00	0.225	0.005
Powell	16.75	0.040	0.010
Rockcastle	8.00	0.015	trace
Rowan	12.50	0.055	0.015
Taylor	27.75	0.165	0.015
Average		0.090	0.009

The above table shows the average combined values of the gold and silver in the shale from twenty-two different counties to be only twenty-four cents, an amount negligible from a commercial standpoint. A glance at series number three shows the average values of the gold and silver content of a series of samples taken at frequent intervals from the top of a shale deposit to a distance of 40 feet from the top to be 24 cents a ton, which goes to show that the precious metal content of the shale is pretty well disseminated throughout the entire district.

The following table shows the shale counties arranged in the order of the value of the precious metal shown:

County	Value of gold and silver per ton of roasted shale	County	Value of gold and silver per ton of roasted shale
Garrard	46 cents	Nelson	24 cents
Cumberland	44 cents	Clark	23 cents
Taylor	41 cents	Powell	23 cents
Elliott	38 cents	Jefferson	22 cents
Casey	36 cents	Marion	12 cents
Bath	34 cents	Lincoln	3 cents
Bullitt	34 cents	Fleming	2 cents
Rowan	34 cents	Boyle	negligible
Lewis	32 cents	Estill	negligible
Montgomery	32 cents	Lee	negligible
Madison	26 cents	Rockcastle	negligible

The following table shows the counties arranged in geographical order starting with Lewis County to the northeast and ending with Jefferson County to the west, also showing the value of the precious metal content of the shale.

County	Value of gold and silver in cents per ton of roasted shale	County	Value of gold and silver in cents per ton of roasted shale
Lewis	32 cents	Garrard	46 cents
Fleming	2 cents	Rockcastle	negligible
Bath	34 cents	Lincoln	3 cents
Rowan	34 cents	Boyle	negligible
Elliott	38 cents	Casey	36 cents
Montgomery	32 cents	Taylor	41 cents
Clark	23 cents	Cumberland	44 cents
Powell	23 cents	Marion	12 cents
Estill	negligible	Nelson	24 cents
Lee	negligible	Bullitt	34 cents
Madison	26 cents	Jefferson	22 cents

The above table was prepared in order to determine, if possible, if there were any well defined streaks of gold and silver values through adjacent counties in the State. Apparently this is only true to a limited extent, if at all, the group of eastern counties, Bath, Rowan, Elliott and Montgomery, showing fairly

uniform values, the group of the southern counties, Casey, Taylor and Cumberland, checking rather closely, the group of the western counties, Nelson, Bullitt and Jefferson, giving somewhat the same results, and the group of counties, Rockcastle, Lincoln and Boyle, showing practically nothing. However, the results shown are not conclusive enough to allow of the drawing of definite conclusions and should only be taken as an indication of what may be expected.

Conclusions

The above experimental work shows that precious metals are present in practically all of the oil shales of Kentucky, but, so far as determined, in small amounts and of no commercial importance, at this time, at least. Nevertheless, it would be advisable on sampling or core drilling a property to have assays made and the precious metal content of the shale determined because the presence of the gold and silver over practically the entire deposit having been proven, there is always the possibility that sufficient natural concentration of precious metals may be found in certain localities to warrant their commercial exploitation. However, commercial amounts of gold and silver should not be assumed to be present in the shale until they have actually been proven, as such an assumption might very well lead to disappointment and loss.

III.

AN ECONOMIC STUDY OF THE BLACK DEVONIAN SHALES OF KENTUCKY

By Charles Stevens Crouse

Oil Shale Technologist

It is an extremely difficult matter to make an economic study of an embryo industry, and unless great care be taken in the sifting of known figures and the prognostication of unknown ones, serious error is apt to result. However, the awakening interest of the public at large in the Black Devonian (oil) shales of Kentucky justifies a serious, conservative attempt to define their economic possibilities and probabilities so far as now known, this being more especially true in view of the mass of information and misinformation, largely the latter, which has been and is being presented by pseudo scientists and others more interested in company promotion than in facts.

The writer, in a recent article,* outlined in a general way, the factors controlling the economic development of the Devonian shales in Kentucky and a more detailed study of these same points will be attempted in the present instance These factors, some of them more vital than others, to be sure, but all of them important, may be summed up under the following heads: (1) Amount of shale available; (2) oil content of shale, both quality and quantity; (3) economic by-products; (4) methods and cost of mining; (5) crushing and retorting; (6) refining; (7) availability of water; (8) transportation; (9) closeness and availability of supplies and market; (10) labor and climate. To the above ten points will be added prospecting, sampling, first cost of land and validity of title, all of which points must be considered and taken care of before any particular property can be developed.

In the following discussion all the factors enumerated above will be dealt with with more or less detail, depending on their relative importance and the data available, but the order in which they have been given will not necessarily be followed.

*Some Economic Aspects of the Kentucky Oil Shales, Combustion, Dec., 1922.

Amount of Shale Available

There are in Kentucky according to W. R. Jillson,* State Geologist, three separate and easily recognizable bituminous shales or groups of shales. First of these proceeding downward in order of superposition is a group of shales found in the Pottsville (Pennsylvanian) at various horizons in the eastern and western coal fields. These shales are generally thin, varying from one to five feet, and are not considered at present of commercial importance.

The second, or next lower, bituminous shale, is the Sunbury, which occurs toward the base of the Waverly (Mississippian). The Sunbury shale varies from 4 feet in Powell County to 16.25 feet in Rowan County. At Vanceburg, on the Ohio river in Lewis County, it is 15 feet thick.

The third and lowest oil shale of present-day commercial improtance in this state is the Chattanooga or Ohio black shale (Upper Devonian).

Although, as shown, there are three shales in Kentucky from which oil may be recovered, nevertheless the term "oil shale" as used in regard to Kentucky deposits means the Devonian black shale plus the Sunbury wherever it may occur.

Prior to that movement of the earth's crust which resulted in the upheaval known as the Cincinnati anticline, no part of the oil shale strata outcropped in Kentucky except, perhaps, along river gorges, though the whole state was underlain with it. Then came the uplift mentioned, and, in the course of time, erosion removed not only the superimposed strata, but the oil shale itself, along with some of the strata beneath, from that section of the state now known as the Blue Grass. This left a ring of shale hills outcropping to the surface all around the Blue Grass section, and thus was the famous knob region of Kentucky formed. The whole state, then, with the exception of the Blue Grass, is underlaid with oil shale, but the principal outcrop of this material occurs, as noted, around the edge of the Blue Grass section, with an outcrop of minor importance in the Cumberland river valley and some adjacent minor streams.

This outcrop shale is found in thirty-three counties in Kentucky, but that of the greatest economic importance occurs in

*Kentucky Geological Survey, Series VI, Vol. II, Paper No. I. 1921.

the beforementioned narrow belt comprising the knob country and it is upon this belt that particular stress will be laid.

It has been conservatively estimated that the outcrop shale areas in Kentucky represent approximately one hundred billion tons, an amount so great as to stagger the imagination. Considering an average of one-half a barrel of oil to the ton of shale, an amount which will be exceeded in some cases, though not reached in others, this shale represents a storage reservoir containing fifty billion barrels of crude petroleum, an amount of oil which has never been and never will be obtained from drilled wells in this country. No fears need be felt for future supplies of motor fuel and lubricants with such a vast source of oil as yet untouched.

Character of the Shale

The shale is rather hard and britle when fresh and the fracture is conchoidal with the surface of freshly broken pieces showing a velvety black color, though weathered pieces show fissibility and a grayish cast. It consists primarily of what, for want of a better name, has been called "kerogen," that is the material which, being subjected to destructive distillation, produces the oil, and of inert, from an oil standpoint, mineral matter. The kerogen portion of the shale is light in weight so that it may be said that, in general, the lighter the shale in weight the more oil may be expected. The average weight of twenty-one samples of shale from as many different counties of the state is approximately 130 pounds per cubic foot.

Analyses of shale from four widely scattered points show the average loss on burning, this includes the oil and gas vapors, sulphur, nitrogen and other volatiles, to be 18.87%, the average silica to be 45.40%, the alumina 19.86%, the ferric oxide 7.96% and the potassium oxide 2.64%, the remaining percentage necessary to make up the 100% being embodied in small amounts of various other materials. Analyses on these samples after burning, that is, on shale about as it would come from the retort after having given up its oils and volatiles, show the average silica to be 57.10%, the alumina 25.12%, the ferric oxide 10.02% and the potassium oxide 3.30%, the remaining percentage being scattered as before.

A CLOSE UP VIEW OF UNWEATHERED SHALE.
This picture shows a freshly exposed shale surface near Clay City, Powell County. Note the typical blocky appearance.

Oil, Fuel Gas and Nitrogen Content of the Shale

During the fall of 1920 the writer collected and subsequently analyzed for oil, samples of shale from some eighteen counties in the state. The results were published by Dr. W. R. Jillson in the article previously mentioned and showed an average yield of about sixteen gallons of oil per ton. Since that time the writer has analyzed a great many more samples of shale and as a result has reached the conclusion that twenty-one gallons, or a half barrel, to the ton is a great deal closer to the true average of the entire shale area than is sixteen gallons. It must be borne in mind, however, that this figure is an average one and that a great deal of the shale will run higher in oil content, even up to thirty-two gallons to the ton or better, while some of it, principally the weathered portions, will run much lower. At the same time from 3,000 to 4,000 cubic feet of fuel gas of a net heating value of around 337 British Thermal units per cubic foot may be obtained and this amount may be materially increased by combining

superheated steam with the fixed carbon of the shale to form producer gas. In addition, an average analysis of eighteen samples from as many different counties shows the nitrogen content of the shale to be 0.4% which, figuring 60% of the total nitrogen as available for forming ammonium sulphate, which amount should be commercially recoverable, would give 37.7 pounds of this valuable by-product per ton of sale.

Distillation tests show the crude shale oil to run unusually high in motor fuel and to give average amounts of good lubricants and other products usually produced in the refining of petroleum.

Economic By-Products

As to economic by-products, only two have been proven and they have both been mentioned, *i. e.,* fuel gas and ammonium sulphate. Nevertheless, there can be no question but that other by-products will be developed, and it may be of interest to indicate from what source these by-products are apt to come.

One of the problems of the shale industry will be the disposal of the vast amounts of spent shale which, having passed through the retort, have been lessened in weight but not in volume. That it will be handled there can be no question, but how much better if all or part of this material might be put to economic use. Some of the possible means of utilizing this spent shale which will bear investigation and research will be indicated in the following paragraphs.

Years ago vitrified brick were made from the raw shale. How much more reasonable to make them from the spent shale, especially when it is borne in mind that considerable deposits of clay which might be utilized for binding, are scattered throughout the state and are often found close to the shale deposits. Also the spent shale itself, as has been shown, averages around 57% silica, which indicates good raw material.

Another possibility is in the manufacture of cement with the use of the excess gas produced from the distillation of the shale as a fuel. Limestone is extremely prevalent throughout the state, and the shale district is no exception. Limestone suitable for mixing with the spent shale for cement purposes would surely not be hard to find within a reasonable distance.

Smelting plants often use part of their waste slag as a road material. The possibilities of using spent shale mixed with refining tars and residues will bear investigation, especially when it is remembered that good roads in the shale country are, at the present time, largely conspicuous by their absence and that as shale plants are opened the need for these same roads will greatly increase.

These few suggestions do not by any manner of means exhaust the potentialities of the spent shale but merely serve to indicate the lines of investigation which seem to show the greatest economic possibilities at the present time.

Topography of the Shale District

As has been previously stated, the cause for all the shale outcrops in Kentucky is erosion, and the streams and the weather acting on the shale strata over a long period of time have carved it into hills, valleys and plateaus, thus forming, as stated heretofore, the knob country of the state. These knobs rise to a height of from fifty to a hundred and fifty feet and more, being, in the shale district itself, composed almost entirely of that material though the higher crests and those lying further back from the outcrop are often capped with limestone. In many cases the knobs are single (see plate on page 65), though generally connected by ridges or hog-backs. The streams, mostly small, though some are of considerable size, have cut out valleys, many of which are rather wide and flat with their lower levels often lying below the level of the shale itself, thus furnishing ideal plant sites and making the application of gravity mining a simple matter.

This section of the state contains the poorest agricultural land in Kentucky, not only because of its topography, with its steep hillsides, but also because the weathered and disintegrated shale makes a poor soil. This applies particularly to the hills where the soil is never more than a few feet thick, and often but a few inches, though in the valleys it is generally of sufficient depth and fertility to be cultivated. Therefore, it may be said that the valley lands of the shale district are practically the only portions that are at all economically important agriculturally.

AN ISOLATED SHALE HILL.
Great numbers of these hills occur in the shale region of Kentucky. More often, however, they are connected by ridges.

The topographical conditions as given are typical for the entire region with one exception and this is along the Ohio river in Jefferson County around Louisville, where the hills have been worn down and the country flattened to such an extent that an overburden of from ten to fifteen feet of earth has been deposited over the shale.

Drainage and Water Supply

Dr. Jillson in "A Preliminary Report on the Oil Shales of Kentucky" has divided the shale area into three parts: The western, embracing the area west and northwest of Stanford; the eastern, embracing the area east and northeast of Stanford, and the southern, embracing the area generally south and southwest of Stanford, including a part of the Cumberland River valley and adjacent watersheds. The natural drainage follows much the same lines, except that in this case the southern and western divisions must be grouped together.

As shown by the general geological map of Kentucky, a plentitude of streams exists throughout the shale district. Some of these streams are large and some small; some permanent and some seasonal, but the topography is such that, if no large, permanent stream is available, dams may be constructed at moderate cost and plenty of water impounded for year-around plant operation.

The entire shale district drains eventually into the Ohio river, the eastern portion through the Licking and Kentucky rivers and their numerous tributaries, and the western and southern areas through the Cumberland, Green and Salt. Of these five major streams only one, the Kentucky, is navigable as far up as the shale country but water transportation of supplies and products on this stream is perfectly feasible as it is being used now for the barging of coal and oil. The Ohio is also available at Vanceburg and Louisville, at which places the shale crosses over into Ohio and into Indiana, respectively.

Climate of the Shale District

As Dr. Jillson has divided the shale area into three parts with Stanford as the dividing line, so has the Weather Bureau divided the state into two parts with Junction City, a few miles west of Stanford, approximately the dividing point. The eastern and southern shale areas fall into the eastern Kentucky division of the Weather Bureau, and the western shale area into the western division. Nevertheless, the climate of the entire shale district is about the same and is comparatively dependable. The winters are rather short and of moderate severity with long summers, which at times becomes rather hot but with, as a usual thing, the heat broken frequently by rains and cool spells. The climate as a whole is delightful with no long continued stretches of either extreme heat or cold, and with long, pleasant springs and falls. From the standpoint of continuous plant operation a more desirable climate could scarcely be hoped for.

The following data concerning the climate of this region was taken from the reports of the United States Weather Bureau and, in general, comprises reports up to and including 1916.

Rainfall

The entire shale district lies within or near the path of the moisture-bearing storms which move from the western gulf region northeastward over the Mississippi and Ohio valleys to the Lake region and north Atlantic coast, the greater portion of the rainfall over the section being obtained from these general storms which vary greatly in frequency, character and force. The records show that there is a wide variation in the amount of rainfall for the individual months, seasons and years though the average annual amount and the average for any calendar

month for a number of years show a rather uniform distribution over the area.

In the eastern section the annual rainfall varies from 40 to 45 inches over the Licking river basin to 45 to 50 inches over the basin of the Cumberland river with the average monthly amounts varying from 2.5 to 3.5 inches in September and October to from 3.5 to 5.5 inches for the other months. The average number of days with appreciable precipitation is about 114 for the year, 5 to 9 for the fall months (September to November inclusive), and 10 to 13 for all other months, though the records show, roughly, about three droughty years in each decade.

In the western portion of the shale district, the annual rainfall is about 45.2 inches, the average for September and October being between 2.5 and 3.5 inches, and the average for the other months being between 3 and 5 inches, these amounts being approximately the same as found in the eastern section. The average number of days with appreciable precipitation in this section, however, is about 104 for the year; 5 to 8 for the fall months and 8 to 13 for all other months, with about three droughty years in each decade.

The following tables show, in table 1, the mean precipitation by months over a considerable period of years at various stations in or near the shale district, and in table 2, some temperature statistics taken at some of the same stations:

TABLE NO. 1

Station, County	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Maysville Mason County	4.08	3.37	4.64	3.45	4.05	4.33	4.36	3.94	2.63	2.49	2.84	3.76	43.9
Farmers Rowan County	4.09	2.98	5.09	4.01	3.75	4.44	5.26	4.93	3.00	3.30	2.57	3.79	47.2
Mt. Sterling Montgomery Co.	4.65	4.12	5.44	3.85	4.33	5.17	5.20	4.07	2.83	2.69	3.34	4.18	49.9
Berea Madison Co.	4.51	3.11	4.77	3.60	4.01	4.81	4.99	4.76	2.73	2.98	2.84	4.54	47.6
Junction City Boyle County	4.47	3.66	4.98	3.66	3.88	3.75	4.34	3.48	3.06	2.25	3.14	4.39	45.1
Burnside Plaski Co.	4.37	4.36	5.13	4.21	4.05	4.28	5.04	4.11	3.29	2.63	3.35	4.12	48.9
Marrowbone Cumberland Co.	4.28	3.17	6.44	4.43	3.32	3.37	5.47	2.84	3.34	1.63	3.05	4.49	45.8
Loretto Marion County	4.52	2.97	4.31	3.49	3.97	4.48	4.20	3.66	2.92	2.44	2.96	4.28	44.2
Bardstown Nelson County	4.58	3.98	4.39	4.00	3.67	4.22	4.41	3.89	2.81	2.40	3.31	4.71	46.4
Louisville Jefferson Co.	4.09	3.90	4.34	4.07	3.72	4.08	3.98	3.32	2.69	2.64	3.69	3.76	44.3

TABLE NO. 2

Station, County	Mean Ann. Snowfall.	Days with .01 or more precipitation.	Mean Jan. Temp.	Mean July Temp.	Mean Ann. Temp.	High Temp.	Low Temp.	Prevailing winds.
Maysville Mason County	18.4	133	33.2	77.2	54.7	108	—22	S
Farmers Rowan County	....	....	36.0	75.0	54.9	104	—16	....
Mt. Sterling Montgomery Co.	22.1	117	33.4	76.3	54.6	104	—22	S
Berea Madison Co.	20.5	118	37.4	76.1	56.6	104	—14	SW
Junction City Boyle County	17.0	107	35.4	75.6	55.2	105	—28	SW
Loretto Marion County	13.8	112	37.2	76.4	56.2	106	—30	....
Bardstown Nelson County	16.4	99	35.8	78.6	57.0	108	—25	SW
Louisville Jefferson Co.	14.7	126	35.0	78.7	57.0	107	—20	SW

Population of the Shale District

The majority of the population of the shale counties is rural and especially is this true of the shale district proper. Table 3 shows that, of the twenty-seven counties under consideration, eighteen of them are classed by the last census as having no incorporated towns of 2,500 inhabitants or over. Of the other eight, the percentage of urban population is low except in Montgomery, Boyle, Clark and Jefferson Counties, where the cities of Mt. Sterling, Danville, Winchester and Louisville respectively, brings the figures up.

However, there are a number of good-sized cities, such as Lexington with a population of 41,534, Ashland with 14,729, Cincinnati with 401,247, Portsmouth, Ohio, with 35,193, Huntington, W. Va., with 50,177, and Knoxville, Tenn., with 77,818, lying within a hundred miles or less of some portion of the shale area. In addition most of the industrial towns of Ohio and Indiana are within a comparatively short distance with direct railroad communication.

The following tables were compiled from data contained in the reports of the United States Bureau of Census and give various population statistics. Table No. 3 shows the counties containing the most important shale outcrops, with their areas, and

population figures for both 1920 and 1910, and the percentage of population which is urban. It must be remembered, however, that only portions of each county contain outcrop shale. Table No. 4 shows the principal incorporated towns in the shale district with their populations, and table No. 5 the principal incorporated towns within a distance of ten miles of the shale, with their populations. A reference to the map showing transportation possibilities will indicate highway and railroad connections.

County	Area in sq. mi.	Population 1920	Population 1910	Per cent Population urban
Bath	270	11,996	13,998	....
Boyle	186	14,998	14,668	34%
Bullitt	308	9,328	9,487	....
Casey	379	17,213	15,479	....
Clark	265	17,901	17,987	34.6%
Clinton	233	8,589	8,153	....
Cumberland	387	10,648	9,846	....
Estill	254	15,569	12,273	17.4%
Fleming	325	15,614	16,066	....
Garrard	237	12,503	11,894	....
Hardin	606	24,287	22,696	10.4%
Jefferson	387	286,369	262,920	84.5%
Larue	288	10,004	10,701	....
Lewis	491	15,829	16,887	....
Lincoln	388	16,481	17,897	....
Madison	446	26,284	26,951	21.4%
Marion	345	15,527	16,330	20.9%
Monroe	441	14,214	13,663	....
Montgomery	198	12,245	12,868	32.6%
Nelson	411	16,137	16,830	....
Powell	181	6,745	6,268	....
Pulaski	628	34,010	35,986	13.7%
Rockcastle	310	15,406	14,473	....
Rowan	272	9,467	9,438	....
Russell	329	11,854	10,861	....
Taylor	279	12,236	11,961	....
Wayne	478	16,208	17,518	....

Note:—All counties for which no percentage of urban population is shown have no incorporated places of 2,500 inhabitants or over.

TABLE NO. 4.
Principal Incorporated Towns in the Shale District.

Town	County	1920 Population
Berea	Madison	1,640
Bradfordsville	Marion	298
Burkesville	Cumberland	798
Chicago	Marion	148
Clay City	Powell	602
Crab Orchard	Lincoln	495
Farmers	Rowan	316
Hustonville	Lincoln	372
Irvine	Estill	2,705
Junction City	Boyle	722
Lebanon	Marion	3,239
Lebanon Junction	Bullitt	882
Liberty	Casey	368
Louisville	Jefferson	234,891
Morehead	Rowan	981
New Haven	Nelson	468
Salt Lick	Bath	518
Shepherdsville	Bullitt	520
Stanton	Powell	311
Vanceburg	Lewis	1,353

TABLE NO. 5.
Principal Incorporated Towns Within Ten Miles of the Shale District.

Town	County	1920 Population
Bardstown	Nelson	1,717
Campbellsville	Taylor	1,535
Danville	Boyle	5,099
Elizabethtown	Hardin	2,530
Flemingsburg	Fleming	1,562
Jamestown	Russell	237
Lancaster	Garrard	2,166
Monticello	Wayne	1,514
Mt. Sterling	Montgomery	3,995
Mt. Vernon	Rockcastle	719
New Albany	Indiana (State)	22,992
Owingsville	Bath	781
Richmond	Madison	5,622
Somerset	Pulaski	4,672
Springfield	Washington	1,529
Stanford	Lincoln	1,397
Winchester	Clark	8,333

Transportation

The accompanying map will give a better idea of transportation possibilities in the shale district than many pages of description could do. The portion of the map cross-hatched represents the generalized shale area, that is, it shows the portion of the state in which outcrop shale may be expected. Not all the portions so indicated show shale, but all the shale in the Blue Grass ring lies in this cross-hatched area. If a more detailed map is required reference should be made to the large geological map of the state published by the Kentucky Geological Survey.

A reference to the map will show that the shale section is rather plentifully supplied with railroad transportation. In the extreme northeast the Chesapeake and Ohio main line from Cincinnati to the Atlantic coast taps it at Vanceburg in Lewis County. Coming south from there, however, there is quite an area untouched by railroads till the main line of the C. & O. from Louisville to the east is reached. This line runs through Mt. Sterling in Montgomery County, Salt Lick in Bath County, and Farmers in Rowan County, all towns in or near the shale. Coming further south the Louisville and Nashville reaches the shale with one branch at Clay City in Powell County and with another at Irvine in Estill County, the former joining the main line between Cincinnati and the south at Winchester in Clark County and the latter at both Winchester and Richmond. At the same time this main line penetrates the shale at Berea in Madison County.

Further west the main line of the Southern passes through the shale country at Junction City in Boyle County, where it crosses a branch line of the L. & N., which parallels the shale hills through Boyle County, passing through Lebanon in Marion County to meet the main line of the L. & N. from Nashville to the south at Lebanon Junction. This main line cuts through the shale just north and south of Shepherdsville in Bullitt County, as shown.

Thus it may be seen that the shale section of Kentucky is very well situated from the standpoint of railroad transportation, there being many commercial deposits directly on a railroad and many more within easy building distance. Another important


KENTUCKY GEOLOGICAL SURVEY
SERIES VI - 1923.
Sketch Map
Showing The
TRANSPORTATION ROUTES
AND OIL SHALE DEPOSITS
OF
North Central Kentucky
SCALE
Miles
0 10 20
LEGEND
GENERALIZED SHALE AREA
RAILROADS
PASSABLE ROADS AS OF JUNE 1923
Ohio
Indiana
OHIO RIVER
CINCINNATI
LOUISVILLE
LEXINGTON
FRANKFORT

point to be borne in mind is that access to any of these railroads is tantamount to direct connection with unlimited markets within comparatively short distances north, south, east and west.

A study of the map also shows that there are a considerable number of highways traversing the shale district, all of them leading to market, and it is also to be noted that only those roads passable or under construction in June of 1923 are shown. More roads are being built right along and, as the shale itself makes an excellent road material, good roads can be easily constructed in those districts which lack them as soon as the necessity arises.

There is also one other form of transportation which, while not generally important in the district, may be a very potent factor in some portions of it, and that is water transportation. The Ohio river cuts the shale at Vanceburg in Lewis County and at Louisville in Jefferson County, while the Kentucky river is navigable up to and considerably beyond Irvine in Estill County.

Thus, taking all things into consideration, it is safe to say that no other shale deposit of comparable size in the United States is as well situated from a transportation standpoint as is the shale district of Kentucky.

Market for Products

The oil shale district of Kentucky is extremely favorably located, geographically, for obtaining its supplies and marketing its products. The eastern half of the United States contains 90% of the population, 80% of the railroad mileage, 87% of the automobiles and has 92% of the capital invested in manufacturing industries, and the Kentucky oil shales, as a glance at the transportation map will show, are in direct, close railroad communication with all this area as well as with the Atlantic sea board for export. In addition there is through railroad communication to the west through St. Louis.

These facts of unlimited market and good transportation with short hauls and consequent low freight rates on supplies and products, give the shales of Kentucky a very marked advantage over the shales of the west.

Value of Lands in the Shale District

The land valuations as shown in table No. 6 were made by the Kentucky State Tax Commission for assessment purposes in 1921 for the counties in the shale district.

TABLE NO. 6.

County	Dollars per acre	County	Dollars per acre
Bath	50.76	Lincoln	43.90
Boyle	75.32	Madison	60.10
Bullitt	23.14	Marion	29.93
Casey	18.76	Monroe	13.77
Clark	97.47	Montgomery	65.60
Clinton	13.51	Nelson	30.59
Cumberland	15.33	Powell	12.06
Estill	14.20	Pulaski	14.09
Fleming	41.51	Rockcastle	11.72
Garrard	72.73	Rowan	7.32
Hardin	20.51	Russell	12.98
Jefferson	132.00	Taylor	17.05
Larue	23.05	Wayne	14.45
Lewis	13.11		

It should be borne in mind that only parts of the counties noted lie in the shale district and that the higher valuations shown are due to this fact, the shale areas themselves being practically valueless agriculturally.

The following table (Table No. 7) taken from the reports of the United States Bureau of the Census for 1920 indicates the area in acres, the percentage of the area in farms, and the average values of farm lands alone, not buildings, of the same counties as shown in the preceding table.

TABLE NO. 7.

County	Approximate land area in acres	Percentage of land in farms	Value of farm land alone in dollars per acre
Bath	172,800	75.4	84.75
Boyle	119,040	93.5	121.36
Bullitt	197,120	81.3	29.88
Casey	242,560	93.4	22.15
Clark	169,600	91.1	147.82
Clinton	149,120	81.4	14.99
Cumberland	247,680	71.5	21.97
Estill	162,560	85.6	20.80
Fleming	208,000	98.2	67.43
Garrard	151,680	85.1	121.18
Hardin	387,840	90.2	34.90
Jefferson	247,680	73.2	121.19
Larue	184,320	80.2	37.04
Lewis	314,240	77.1	18.20
Lincoln	216,320	77.6	70.99
Madison	285,440	89.5	95.09
Marion	220,800	85.1	42.49
Monroe	282,240	72.1	18.83
Montgomery	126,720	92.8	140.26
Nelson	263,040	87.0	55.23
Powell	115,840	77.9	18.30
Pulaski	401,920	83.6	22.58
Rockcastle	198,400	87.3	15.51
Rowan	174,080	76.0	10.10
Russell	210,560	74.3	19.64
Taylor	178,560	92.6	32.59
Wayne	305,920	88.4	17.31

Homogeniety of the Shale

An extremely important factor in the economic exploitation of shale will be the continuity of values throughout the particular deposit being worked. Exhaustive data upon this subject have not been obtained nor are they apt to be obtained till diamond drill prospecting and sampling, as later explained, has been done. Nevertheless, sufficient information has been secured at various deposits here and there throughout the shale district to

apparently prove that there will be very little, if any, variation in values within a specific deposit, weathered shale not being taken into consideration, and also to show that there seems to be a remarkable homogeniety throughout the shale district as a whole.

To be sure small clay seams and partings are found at various points in the shale area, as are lumps of iron sulphide (pyrites) of varying size but, nevertheless, it will be perfectly safe to assume that all the shale in a deposit may be mined and retorted or, in other words, there will be no necessity for selective mining. This situation is in marked contrast to that of the majority of the western shales, where the workable seams are relatively thin and, being covered with non-workable material, will have to be mined by underground methods of mining. The great advantages of a homogenious formation such as that found in Kentucky are self-apparent.

Selection of Plant Location

In examining the shale district for a plant location the first things to be considered are proximity of transportation and water. Practically any location chosen would be close to water but not all have means of transportation available. After having found a site near water and transportation the topography of the ground should be considered. If possible the shale should average about fifty feet thick, or more, lie in hills and ridges without any capping, and there should be enough valley space for a plant site with the floor of the valley below the bottom level of the shale, if possible, so that the material may be handled as much as may be by gravity from the quarry and through the retort. Fortunately these conditions are found to be pretty general throughout the shale district. In addition plenty of space to take care of the spent shale must be provided.

The amount of land to be acquired will depend largely on the daily capacity of the plant to be built, the desired life of the operation, etc., and tables No. 8, and 9 and No. 10 may be helpful in determining this factor.

Table No. 8 shows the number of tons of shale in tracts of varying sizes and with shale of varying thickness.

TABLE NO. 8.

Thickness of deposit in feet	1 acre	10 acres	40 acres	160 acres
1	2,831	28,310	113,240	452,960
5	14,155	141,550	566,200	2,264,800
10	28,310	283,100	1,132,400	4,529,600
15	42,465	424,650	1,698,600	6,794,400
25	70,775	707,750	2,831,000	11,324,000
50	141,550	1,415,500	5,662,000	22,648,000
75	212,325	2,123,250	8,493,000	33,972,000
100	283,100	2,831,000	11,324,000	45,296,000

Table No. 9 shows the barrels of oil obtainable from tracts of varying size and with shale of varying thickness assuming a half barrel of oil to the short ton of shale.

TABLE NO. 9.

Thickness of deposit in feet	1 acre	10 acres	40 acres	160 acres
1	1,415	14,155	56,620	226,480
5	7,077	70,775	283,100	1,132,400
10	14,155	141,550	566,200	2,264,800
15	21,232	212,325	849,300	3,397,200
25	35,387	353,875	1,415,500	5,662,000
50	70,775	707,750	2,831,000	11,324,000
75	106,162	1,061,625	4,246,500	16,986,000
100	141,550	1,415,500	5,662,000	22,648,000

Table No. 10 shows the life, in years of 350 days, of various shale tracts, assuming a daily plant capacity of 1,000 tons.

TABLE NO. 10.

Thickness of deposit in feet	40 acres	160 acres	320 acres	640 acres
25	8.09	32.36	64.72	129.44
50	16.18	64.72	129.44	258.88
75	24.27	97.08	194.16	388.32
100	32.35	129.40	258.80	517.60

After the property has been carefully selected it should be optioned, if possible, and then prospected and sampled before a plant is built. The best and practically the only feasible way of getting absolutely reliable data on the oil content of a deposit is to do systematic diamond drilling and any preliminary money spent in this way will be more than well spent.

The method of procedure would be somewhat as follows: The property would be divided into squares of perhaps 300 feet on a side and a diamond drill hole would be put down on each corner. Then the cores from drilling would be split, one-half being kept as a record and the other half being tested, in five-foot samples, for oil content. On the completion of this work sections of the entire deposit would be made and an accurate knowledge of the oil content of any part of the deposit would be known as would the location of any small partings or occurrences of that nature. This would permit the laying out of a systematic plan of quarrying, so that the shale delivered to the retorts would be of the same general character from day to day and from week to week, prior to the starting of actual mining and would eliminate guesswork and hit or miss development as much as is humanly possible.

The cost of this drilling should not be excessive as the holes drilled would be shallow, seldom more than one hundred feet deep, and the shale itself is not hard to drill. The work could be done by contract with one of the diamond drilling companies or, if the size of the property warranted, a small gasoline operated drill sould be purchased for around $5,000 and the work

done by the shale company itself. No matter which way is chosen, the work should be done as it is the only way in which an accurate idea of the values throughout the property may be obtained before actual mining is initiated. Given the information obtained through diamond drilling, the layout of the quarry, trackage, plant, etc., can be decided on intelligently and the operation carried on systematically.

A TYPICAL SHALE EXPOSURE IN A CREEK BED.
This picture shows shale exposed in the bed of Gum Sulphur Creek, Rockcastle County.

Diamond drilling of shale land has not been done to any extent as yet, although one or two of the companies in that business have done a little, but not in Kentucky. The E. J. Longyear Company of Minneapolis has operated drills at DeBeque, Colorado, for the Ventura Consolidated Oil Company and at Rifle, Colo., for the Pure Oil Company, and they state that "Colorado oil shale on the whole drills and cores well." In one hole in Colorado they obtained a core recovery of 95% and they further say that "an average of 15 to 20 feet per shift while actually drilling would be a fair rate of progress," and again, "carbon

loss is only a few cents per foot, except for the occasional breaking that may be expected in any kind of drilling."

Diamond drill holes in Kentucky shale would be much shallower than those necessary in the west, and therefore a smaller and cheaper drill could be employed by those companies who wished to purchase and operate their own. For this purpose a gasoline drill mounted on a truck and drilling a 15/16 inch or 1 1/8 inch core would be satisfactory. Such an outfit would weigh about 2,500 pounds and cost around $1,750, with an added cost of about $1,000 for drill rods and $2,000 for diamonds.

The value of farm lands in the shale country has been discussed but the statistics given are apt to be somewhat misleading as the shale hills are worth much less agriculturally than the surrounding bottom lands. The shale land that has been already purchased in this state for the purpose of exploiting the shale, has been bought at from $30 to $50 an acre, depending on the amount of real farm land in the tract under consideration and all purchases have been made outright, not on a royalty basis, a procedure that should be generally followed in Kentucky.

There is yet another point that should be mentioned in connection with the acquisition of shale property in Kentucky, and that is the question of titles. None of the land in Kentucky is divided into sections as in the newer states, neither is there any government owned land remaining, but rather was the land parceled out in the earlier days in the form of large land grants. Then these grants were broken up and sold piecemeal and resold again and again, in some cases, and often with no official record of the sale. Especially is this true in the mountain country and in the shale district, where the land was thought to be of very little value at the best. An example may suffice to illustrate the point. Jones owns a farm and sells it to Smith. The farm may be far from the county seat and Smith doesn't take the trouble and go to the expense of having the sale recorded as everybody in the locality knows that it belongs to him. Then he or his heirs may sell the farm to Brown, again without having the deed recorded, and so on. All this time, so far as the records show, the farm belongs to the original owner, Jones, or his heirs. It can readily be seen what a tangle this sort of procedure could leave things in. Consequently a very careful ex-

amination should be made of all titles before purchasing shale lands, and this examination should be made, preferably, by some one familiar with the Kentucky mountaineer and the status of titles in the district.

The above mentioned points give in a general way the factors to be considered before buying shale property. The following pages will attempt to enumerate the fundamental conditions of shale plant operation.

Methods of Mining

It is under this heading that the most marked advantage of Kentucky shales over those of the west is found. As already indicated most of the western shales will have to be mined underground by methods similar to those used in coal mining, while all of the shale in Kentucky under discussion may be mined by open cut or quarry methods at a cost, conservatively estimated, of about a third of the former method. This cost figure is based on the mining of coal and, oil shale being tougher and harder to mine, the cost of underground mining of this material will very likely be greater than that assumed, thus giving a still greater advantage to Kentucky shale. In corroboration of the above statement regarding mining of western shales, Martin J. Gavin, Oil Shale Expert of the United States Bureau of Mines, who has done an immense amount of work on the western shales, says: "Oil shale is tougher than coal; most of the deposits are horizontal or nearly so; and those of the Rocky Mountain Region usually outcrop high up on the walls of canyons and lie at altitudes of from 5,000 to 8,000 feet. In such cases most mining engineers believe that oil shales will be mined by methods similar to those used in coal mining, and at a similar cost. The impression has been created that shale can be mined by open cut or quarrying methods, permitting the use of steam shovels. While this is undoubtedly true of some shales in the eastern states, there are probably few deposits in Colorado, Utah or Wyoming where steam shovel methods can be employed. It is now considered that most of these oil shales will be mined by underground methods similar to those used in coal mining."

The Kentucky shale formation lies in a nearly horizontal position with, generally speaking, practically no overburden on

it, what there is being largely composed of a few feet of weathered and decomposed shale. This overburden will practically never have to be removed separately but can be mined with the shale itself and fed direct to the retorts. For this type of deposit quarrying or open cut methods of mining will prove to be by far the most economical and practical, especially when the fact that most of the shale lies above the level of the surrounding country is taken into consideration.

Whether quarrying in a strict sense of the word will be used or an open cut method will depend of the topographical condition of the individual shale tract. If the shale occurs in hills, as is usually the case, quarrying, with or without steam shovels, may be employed, but if the tract is level an open cut system, with the use of steam shovels, is indicated.

The advantages lying with either one of the above methods are many, including as they do, low cost of mining with large percentage of recovery, large production with ease of supervision and few skilled laborers, convenient and efficient use of explosives and, the operations being conducted in daylight and the open air, there is no need for ventilation to rid the mine of poisonous or explosive gases, which fact makes for the health of the workers and a high degree of safety. In addition to these general advantages, which apply equally well to quarrying and open cuts, the hillside type of quarry has the further advantages that it is largely self-draining, the shale can be handled by gravity and less drilling and explosives will be needed to break an equal amount of shale.

Blasting and Loading

Up to the present time there is no direct data available on drilling, blasting or loading oil shale, but shale, though it may be a trifle tougher, is very similar in its occurrence to a tough limestone and the methods used in quarrying will also be comparable. As a result statistics on the quarrying of limestone should be very valuable as indicating methods to be followed and costs to be expected in mining the Kentucky shale.

Considerable data has been collected and published concerning the economics of limestone and the writer has drawn liberally on this information in compiling the following pages, but he

wishes to acknowledge his especial indebtedness to Mr. Oliver Bowles, Mineral Technologist of the United States Bureau of Mines, who has made this subject a special study, for his kindness in placing valuable data at his disposal.

Considering the size of material broken there are two extremes in blasting; either to break the material into pieces of maximum size or to break it very fine, and the manner of drilling, blasting, kind of powder employed and amount used will vary materially with the method used. The blasting of shale lies midway between these two extremes and may be likened to the practice at the limestone quarries where the stone is to be burned to make lime. Because of the fact that dust makes trouble in retorting, the shale must be broken down with a minimum of fines and if a large proportion of the fragments are 4 inches and over the practice may be considered good. As a matter of course a minimum of pieces too large to enter the primary crusher is most desirable, as otherwise the cost of breaking will be increased due to the necessity of further blasting or block holing these large pieces.

Drilling

In the following discussion of drilling it will be assumed that the shale is being mined by quarrying in a hillside as this is the condition which will largely prevail in actual practice. Such being the case there are three types of drill which may be used—hand manipulated air hammer drills, tripod drills, and churn drills.

The first type, though it may be used for primary drilling, has a field of its own in secondary work or block holing of large fragments. This is true because even though it is more rapid in operation, may be more easily moved from point to point, and may be held in the hand even for holes of from 12 to 20 feet in depth, nevertheless the size of steel used is small, the drill making, in consequence, a small hole. The ordinary hammer drill starts a hole with 1.5 inch steel while the tripod drill uses 2.25 inch stuff, which means that the depth needed to hold 4 pounds of dynamite in the first case would hold 9 pounds in the second.

For these reasons the tripod has seen very wide usage, but in recent years the churn drill has very largely replaced it as it is pretty generally considered that it saves both time and money in large scale work. One of the outstanding advantages is the substitution of a single bench the full height of the face for a series of benches which, in turn, eliminates the danger to workmen of rock fragments falling from one bench to another, loss in production where men are watching for dangers from the bench above, and the unnecessary complications of transporting loaded shale from different levels. Another decided advantage is that churn drill holes are of the same size at the bottom as they are at the top while both tripod and hammer drill holes diminish in size from top to bottom. This means that the smaller holes have to be "sprung" with dynamite in order to give room for the explosive, while churn drill holes ordinarily require no springing.

As the primary object of drilling is to obtain space for the explosive, the only fair method of comparing drilling cost is not in terms of cost per foot but rather on the basis of volume of space obtained. It can readily be seen that a 6 inch hole, which is the general size made by a churn drill, has nine times the volume of a 2 inch hole of the same depth so, if no springing is used, it will require nine 2 inch holes to provide explosive space equivalent to that supplied by one 6 inch hole. The question in this case would be, then, is the cost per foot of the churn drill hole nine times that of the other?

Another great advantage of churn drilling is the fact that great masses of material may be broken at one time, often enough to last several months, thus obviating the frequent stoppages of work necessary when blasting at shorter intervals.

The most advantageous conditions for churn drill operation are when the quarry face is from 30 to 100 feet high, a condition which will be practically universal in the shale district. Under these circumstances an average of from 50 to 60 feet could probably be easily drilled in shale per ten-hour day. The Loomis Machine Co. estimates the cost of drilling a 5 5/8 inch hole, electric power being used, as about $14.00 per ten-hour day which, on the basis of 50 feet per day, would give a cost of 28 cents a foot.

Arrangement of Churn Drill Holes

According to Russell (Pointers on the Use of Explosives in Quarry Blasting, Cement Mill and Quarry, Jan. 20, 1922), a single row of holes is probably the best where the quarry face is 50 feet high or over. Where the face is 20 to 30 feet in height, two to five rows of holes may be shot at one time. Where two or more rows are shot at one time the alternate rows are usually staggered. The burden (distance of hole from face) and spacing (distance from hole to hole in the row) may vary considerably in different types of stone. It is probably better to begin with a close spacing and gradually increase it till the maximum spacing that will shatter the rock properly is attained. In an average limestone worked from a quarry with a 35 to 40 foot face the spacing should be 10 to 12 feet and the burden 12 to 15 feet. Both spacing and burden should increase with increasing depth of holes, but should rarely exceed 20 to 25 feet for the deepest holes. The holes should also be extended about five feet below the level to which it is desired to break in order to clear the toe.

Reeves in "An Economic Study of the New Albany Shales" quotes S. R. Russell as saying that about 32 tons of the New Albany shale (which is practically identical with that occurring in Kentucky) would be moved for each foot of drill hole where holes are spaced 20 feet by 20 feet. Accordingly, on the basis of 40 feet per day, the cost of drilling would be approximately one cent per ton of rock broken.

Explosives

Ammonia dynamite is probably the most common explosive used in quarry work, though gelatine dynamite should be used in wet holes. For shale work explosives with a high rate of detonation should probably not be used as they tend to shatter the rock too much, and thus produce fines. Dynamite of from 30% to 40% strength will likely be found to be the most satisfactory.

The determination of the amount of explosive to be used is too often left to the judgment of the man in charge, when it should be regulated in accordance with the estimated amount of rock to be moved. The tonnage to be expected from any particular drill hole may be easily obtained by multiplying the bur-

den in feet by the spacing in feet by the depth of the hole in feet. This will give the number of cubic feet of shale. Then by multiplying this figure by the weight of a cubic foot of shale, 130 pounds, and dividing by 2,000, the tonnage is obtained. Thus, if the burden is 20 feet, the spacing 20 feet, and the depth 40 feet (to make the figures the same as those given by Russell on New Albany shale), the number of tons to be moved by the explosive in each drill hole would be $\frac{20x20x40x130}{2000}$ or 1,040 tons.

No absolute figures on the amount of powder to be used can be given unless the problem is specified in particluar. However, it may be said that in the average quarry work from 3 to 6 tons of rock are broken for each pound of 40% ammonia dynamite used. The first charge should be estimated on an average basis, say 4 tons per pound, which would indicate that for the drill hole given above 260 pounds of dynamite would be a reasonable charge. When the blast is shot the results will indicate whether the charge were too light, too heavy, or correct, and the proper corrections may be made. In addition, where more than one row of holes is shot at one time, the back holes should contain at least 10% more explosive than the front row. A shorter burden for the back rows is also advisable. In any case, however, the cost of explosive for shale quarrying cannot be more than a few cents, possibly 3 or 4, per ton of rock broken

Loading

The largest single item of quarry expense is probably the loading of the rock after it has been blasted down. For small operations where capital is limited, hand loading or loading with drag line or scrapers will probably be employed, but in large operations, say from 500 tons daily capacity and up, steam shovels should be used.

The advantages of steam shovel loading are many, among which may be enumerated the ability to handle rocks of any weight so long as they can be picked up in the dipper, thus eliminating a large part of the secondary blasting or block holing, and the fact that for equal tonnage produced a much smaller gang of men is required than with hand loading. Bowles states in "Rock Loading at Lime Plant Quarries," that the Bureau of Mines compiled figures a few years ago which showed that in

fourteen quarries where steam shovels were used an average daily output of 112 tons per man was obtained, taking into consideration only pit and shovel men, while in eleven quarries in which hand loading was used the daily tonnage per man, loaders only, was 16 tons.

However, in order to insure efficient steam shovel loading, care should be taken to see that blasting is done in such a way as to throw down large volumes of rock at one time and also that the trackage be so arranged that empties may be placed and loaded cars removed with the least possible loss of time. It naturally follows that there should also be a sufficient supply of cars so that small delays at the crusher need not interfere with loading because of a shortage of empties.

Manifestly, the extent of the operation will govern the size of the shovel used, and figures will be given for an operation with a 500 ton a day capacity and for one with a daily capacity of 1,000 tons.

For the former, 500 ton daily capacity, the Bucyrus Company of South Milwaukee, Wis., advises, in general, for Kentucky shale, the use of their 20-B revolving shovel, caterpillar mounted, which sells for $9,600 f. o. b., Evansville, Ind., (quotation June 19, 1923). This shovel has a ¾-yard dipper and the ease with which it may be handled makes it possible for an average man to maintain a working speed of from 2.5 to 3.5 dippers per minute.

For the second case, the 1,000 ton daily capacity, they advise the use of their 50-B revolving shovel, caterpillar mounted, which sells for $20,800 f. o. b. Evansville, Ind. (quotation June 19, 1923), this being a 1¾-yard shovel. They also advise the use of 4 or 5 yard narrow gauge cars for transporting the shale from the face to the plant, the 4 yard cars selling for about $470 and the 5 yard ones for about $495 apiece. Of course, it would be necessary to have sufficient cars to form two trains so that one might be loading while the other was on its way to the plant.

The Marion Steam Shovel Company, of Marion, Ohio, tentatively advise the use of their model 21, caterpillar mounted, revolving shovel, with a ¾-yard dipper for the 500 ton daily capacity and their models 32 or 37 for the 1,000 ton a day

plant. Both of these shovels may be obtained caterpillar mounted and are of the revolving type, the former having a 1 1/4 yard dipper and the latter one with a capacity of 1¾ yards.

Regarding the cost of operation the Bucyrus Company gives very full information on this subject in its "Handbook of Steam Shovel Work," a careful study of which is recommended prior to commercial operation. However, it may be noted that the union scale for shovel operators is $225 per month and for firemen $175. Furthermore, about two pit men will be required at the rate of pay prevalent at the particular place under consideration, probably $3 a day being an average figure.

The following tables will give some idea as to the shovel costs to be expected in both cases cited, though it must be remembered that local conditions will govern and may increase or decrease the figures as given.

TABLE NO. 11.

The figures in the table are for a ten-hour day and a 500-ton daily capacity.

One shovel runner	$7.50
One fireman	5.75
Two pit men	6.00
One ton of coal	7.00
Oil and grease	2.00
Interest at 6%, depreciation at 4⅔%, repairs	6.50
Total	$34.75

This will give an average figure of about 7 cents a ton for loading which ought to be fairly representative for shale work.

TABLE NO. 12.

The figures in the table are for a ten-hour day and a 1,000 ton daily capacity.

One shovel runner	$7.50
One fireman	5.75
Two pit men	6.00
One and one-half tons of coal	10.50
Oil and grease	3.00
Interest at 6%, depreciation at 4⅔%, repairs	14.25
Total	$47.50

This will give an average figure of about 5 cents per ton.

Haulage

This takes into consideration the motive power and equipment required to convey the shale from the loading place at the quarry face to the bins in the crusher house and involves trackage, cars, and haulage system employed.

The arrangement of the track depends upon the loading method used, and also upon the layout of the quarry. For hand loading it is advantageous, in order to maintain maximum output, to provide a number of working places with independent trackage from the main line to each place. For steam shovel work, however, the car track will be placed parallel to the face so that as one car is loaded the train may be moved forward to furnish an empty.

The transportation problem in Kentucky shale quarries should admit of a simple solution as the occurrence of the shale in hills will make it feasible, generally, to place the retorting plant below the bottom level of the shale, thus making it possible to utilize gravity to the fullest extent. However, a few general observations on the subject may not be out of place. The rails used should be heavy enough to stand up to the work demanded of them, the roadbed should be kept in good condition, and the cars for steam shovel loading should be strong and durable and a sufficient number of them should be maintained so as to eliminate, as much as possible, any stoppage of the shovel. As to motive power, it will probably be best to use small steam locomotives or "dinkeys" which will handle from five to fifteen cars at a time.

Costs of haulage cannot be estimated in general as conditions will vary so largely in the individual quarries, but they should not be high even in extreme cases and in the majority they should be low.

Breaking

The shale will go direct from the quarry to the storage bins and from these to the crushing plant. The size to which the shale will have to be crushed will depend entirely upon the type of retort used, some requiring very fine material and some coarse. However, in all cases, the crushing of the shale must be done in such a way as to produce a minimum of fines, as the presence

of excessive dust will cause retorting trouble in practically any form of apparatus that may be used. Fortunately the Kentucky shale crushes rather easily without gumming and the production of less fine material than soft limestone or sandstone.

During the spring of 1923 tests were conducted in the Mining Laboratory of the University of Kentucky by Messrs. P. C. Emrath and M. T. Skidmore, under the supervision of the writer, to determine, so far as possible with the facilities at hand, the best method or methods to be employed when crushing Kentucky shale on a commercial basis. The size desired was chosen as that which would pass over a screen having eight openings to the linear inch and through one having four openings to the linear inch. This size was chosen to conform to the size found most suitable for a semi-commercial retort which was available. In the tests carried on twelve samples of 100 pounds each were run through a series of crushers, the crushing of each sample being followed by screening into three parts, namely, oversize, correct size and fines. Hand screens were used and several different motions were imparted to them so as to determine, if possible, what type of screening apparatus would be most desirable. A gyratory breaker was used to break the shale from mine run size to 2.5 inches, then a small jaw breaker was employed, followed by a small pair of rolls. The material was screened after each operation and was fed to the jaw breaker and rolls both by free feeding and choke feeding.

The conclusions arrived at were that, for commercial operation, a large size gyratory breaker should be used for the shale as it comes from the quarry, followed by screening through revolving trammels built of slotted plate screen, followed by choke fed rolls with subsequent screening to remove fines. In regard to the manner of feeding, it may be said that although choke feeding gave a somewhat greater percentage of fines, on the other hand it gave a lesser percentage of oversize to be recrushed so that taking the other advantages of this form of feeding into account, such as conservation of time and increased output, choke feeding seems to be the better.

The layout of a crushing plant of this sort will vary considerably with local conditions, in fact, depend entirely on them. A location on a natural slope such as a hillside will be found to

be the best possible, because of the ability to move the shale almost entirely by gravity with the result that little or no conveying equipment will be required. Fortunately this type of site will be found in all, or practically all, locations in the shale district.

The Allis Chalmers Manufacturing Company of Milwaukee, Wis., makes the following recommendations, of a general nature, regarding the crushing equipment for both a 500 and a 1,000 ton plant. In this case, as in the case of steam shovel work, a ten-hour day has been assumed. As the retorts must run twenty-four hours a day, this means that there must be sufficient bin room or storage capacity to supply the needs of the retorts during the time that the shovel and crushing plant are idle, with an additional capacity to insure against stoppage of retorting in case of a temporary shut down because of accident or other causes.

For the 500 ton daily capacity the Allis Chalmers Company suggests reducing the shale as quarried in one of their 7½ style K gyratory crushers to 2.5 inch size. In the event that an appreciable percentage of the 2.5 inch size exists in the shale as quarried, the material could be fed to the crusher over a stationary grizzly. After having the undersize screened out in a slotted plate screen trommel, the oversize would be led to one of their 54x24 Anaconda rolls where it would be further comminuted to the size desired. In any case it would be the better part of wisdom to remove all dust from the crushed shale before feeding to the retort. This dust need not be wasted but could be utilized in the manufacture of gas.

The gyratory crusher specified above weighs 70,000 pounds, takes 60 to 75 horse power to operate and costs $5,800 f. o. b. Milwaukee (quotation June 20, 1923). The 54x24 Anaconda roll weighs 94,000 pounds, takes 75 horse power to operate and costs $7,500 f. o. b. Milwaukee (quotation June 20, 1923).

For the 1,000 ton a day plant the same company suggests reducing the quarried product to 5 inch size through one of their 36x48 inch jaw crushers, the discharge from which might be led to two of their No. 6 style K gyratories, where it would be reduced to a 2 inch size. This product could then be fed to two 54x24 Anaconda rolls for the final reduction. What has been previously said in regard to screening applies equally well in this case.

The jaw crusher specified weighs 130,000 pounds, takes 125 horse power to operate and costs $16,000 f. o. b. Milwaukee (quotation June 20, 1923). The No. 6 style K gyratory crusher weighs 47,000 pounds, consumes from 40 to 50 horse power and costs $4,200 f. o. b. Milwaukee (quotation June 20, 1923), while the Anaconda rolls are the same as given in the preceding case.

The inside operation of either of these plants, under ordinary circumstances, should be successfully carried on by two or perhaps three men, inasmuch as none of the equipment requires very much attention. Very little can be said regarding power cost except that it may be figured from the horse power required and the cost of this power under local conditions.

A slightly different arrangement of the crushing plant is suggested by the Traylor Engineering and Manufacturing Company of Allentown, Pa. They recommend the following machinery for a 50 ton an hour (500 ton a day) plant: one 14-inch gyratory crusher, set for a 2½-inch product; one 40-inch by 10 foot revolving screen; one 6-inch finishing gyratory crusher, set for 1 inch product; one vibrating screen to take the finished sizes out of the crusher product; one 36-inch by 16-inch roll, set for 1/4-inch size; one vibrating screen to separate the roll product and return the oversize for further crushing.

For a 100 ton an hour (1,000 ton a day) plant the following machinery is recommended: one 16-inch gyratory crusher, set for 3-inch product; one 48-inch by 10-foot revolving screen; two 6-inch finishing gyratory crushers, set for 1-inch product; the necessary vibrating screens to take the finished sizes out of the crusher product; one set of 54-inch by 24-inch rolls, set for 1/4-inch product; the necessary vibrating screens to separate the roll product and return the oversize for further crushing. If steam shovels are used in the quarry, as will probably be the case, it will be necessary to use a breaker with a larger opening than 16 inches. Therefore, in that case, a 36-inch by 48-inch jaw crusher, to be placed ahead of the 16-inch gyratory crusher, is recommended as ample, even with a large shovel.

In addition to the above equipment elevators or conveyors will be necessary, though they cannot be definitely determined till the arrangement of the plant has been decided on. However, the Traylor Company states that, "ordinarily we would set the

primary crusher on one side of the elevator and the secondary crushers on the other. All of the crushers discharge into the elevator and elevate the material to the primary screen. Directly below the primary screen we would place the first vibrating screen to take out the finished product, the oversize going to the rolls. This material should then again be elevated to the final screens and the rejects returned to the roll."

As far as the cost of the crushing in the above outlined plant is concerned, it is difficult to give definite figures without the benefit of actual experience but, comparing with other plants, the Traylor Company estimates the cost of crushing as from six to ten cents per ton of shale. The cost depends to quite an extent, also, on the care the machinery is given, a poor operator being very apt to ruin the apparatus in less than a year while an experienced, careful man might run the plant for ten years with very little trouble and few repairs.

In regard to the power required the above company states. "The power required per ton of rock per hour would be about $2\frac{1}{2}$ horse power. One-half horse power should be included besides this for the elevators and screens, making a total of three horse power per ton of rock per hour or 150 horse power in the small plant and 300 in the large plant." If the large jaw crusher is used, as in steam shovel operation, its power consumption would be about one-half horse power per ton per hour.

The item of wear and tear depends, as has been stated, on the operators and the nature of the material, but the Traylor Company believes that, for the above plant, 5% per annum would be sufficient to allow for replacements.

The upkeep of the plant is an exceedingly variable factor. The principal source of this item is, manifestly, due to the wear on the crushing surfaces, and this will vary both with the sort of material crushed and with the material from which the crushing surfaces are made. However, the following figures will give the average rate of the consumption of the crushing plates from which, knowing the cost of the particular material that is being used, the upkeep cost may be figured. For the gyratory crusher the wear on the crushing plates is 1/50 of a pound of liner material per ton of shale crushed, for the jaw crusher 1/40 of a pound, and for the rolls 1/15 of a pound per ton.

Inasmuch as accurate information on a particular installation is necessary before giving more than general cost information, it is recommended that further operating costs should be left to be determined from actual conditions.

Retorting and Refining

The next step in the process of producing shale oil is the eduction of the oil from the shale, or retorting. The method used is that of destructive distillation. This means that heat is applied to the crushed shale, which heat changes the "kerogen" of the shale into gas, part of which is condensed and forms the oil and part of which is non-condensable and forms a fuel gas which, furnishing the fuel for the entire operation, is a most valuable by-product.

No attempt will be made to go into the chemistry of the retorting process nor to discuss the relative values of the different types of retorts that have been devised, the latter having been done by the writer so for as Kentucky shales are concerned, in a previous paper (Retorting Methods as Applied to Kentucky Oil Shales, Sixth Geological Survey, Kentucky Geological Survey). However, it may be said that any retort to be commercially successful should be mechanically simple, be continuous, have a good throughput per day, have a low upkeep, a moderate operating cost and be able to do the work that it is expected to do. This latter point means that the crushed shale should be subjected to a temperature gradually rising to the maximum of about 900 degrees F., for at least 45 minutes, without access of air, and that the gases should be withdrawn through the cooler portions of the retort so as to avoid, as much as possible, the cracking of the oil gas into fuel gas.

The Kentucky shales are probably more like the Scotch shales than any others in this country, and offer no particularly difficult retorting problems, there being several machines in the market that could probably be used satisfactorily on these shales at the present time. However, there are a host of others being presented to the prospective oil shale operator which have no value whatever, and a most careful examination and testing, together with consultation with the best authority should be taken

before adopting any retort for a commercial plant. It is impossible to lay too much emphasis on this point.

It would be folly to attempt to give any retorting costs without a knowledge of what form of retort was to be used, but, nevertheless the fact remains that, considering that the retort selected is properly designed, the cost should be low, as the fuel, the chief item of expense, will be furnished by the fuel gas produced in the retorting operation itself. However, waste heat boilers should be placed in the flues in order to utilize the excess heat in the waste gases, in raising steam. Especially is this the case when superheated steam is to be used in the retorting process itself and this will pretty generally be done as its use increases the output of oil materially. Probably a large proportion of the steam used around the plant, both for retorting and power purposes, can be supplied through waste heat boilers if properly designed and operated.

In connection with the retorts proper there will have to be condensing apparatus, scrubbers to remove the light oil carried mechanically in the fuel gas stream, scrubbers to remove the ammonia gas and a sulphate plant to recover the ammonia as ammonium sulphate. Of course, this latter will not be needed unless the ammonia is to be recovered but, because of the high nitrogen content of the Kentucky shale, its recovery here should be commercially successful. In addition gasometers for storing the fuel gas and a tank farm for crude oil storage along with conveying apparatus to remove the spent shale after it leaves the retorts and take it to the dump, are indicated.

One of the first and most important factors to be determined is what is to be done with the main product of the retort, the crude oil, after it is obtained. Three general possibilities present themselves: (1) It may be sold direct to refineries. Due to the fact that the methods used in refining crude shale oil will be somewhat different from those used in refining crude well oil as good a price could probably not be obtained from refineries at the present time for crude shale oil as for crude petroleum. In the future, when refinery men have been educated up to shale oil as good or even a better price may be obtained, but this would probably not be the case now; (2) a topping plant might be erected which would make motor fuel and fuel oil. This would

probably be the best practice under existing circumstances, as such a plant could be erected at comparatively small cost and a barrel of crude oil split into motor fuel and fuel oil would bring a much better price than though sold as crude. Especially is this the case in view of the high percentage of motor fuel in the Kentucky crude shale oil; (3) a complete refinery might be erected and all the usual refinery products made. This last method would probably give the highest monetary return in the long run but presupposes a large operation and plenty of capital at the start. This latter stage should develope naturally from a plant that has started operations with only a topping plant and it would probably be best to work toward this end rather than to try to start operations so equipped.

The following table, taken from J. E. Pogue's "The Economics of Petroleum," shows the estimated average returns per barrel of crude petroleum refined in 1918, and serves to emphasize the fact that motor fuel is the most valuable part of the oil. What was true in 1918 is even more true today, which would again indicate the wisdom of starting operations with a topping plant only.

TABLE NO. 13.

Estimated average return per barrel of crude petroleum refined in 1918.

Rank	Product	Dollars	Percentage of total
1	Gasoline	1.922	44.5
2	Gas and fuel oil	1.213	28.2
3	Lubricating oils	.419	9.7
4	Kerosene	.378	8.8
5	Wax	.121	2.8
6	Asphalt	.042	.95
7	Coke	.0069	.15
8	All others	.21	4.9
		4.31	100.00

The cost of either a topping plant or a complete refinery for shale oil will be about the same as one of the same capacity

treating well petroleum as the methods used will be very similar and no unusual difficulty is to be anticipated in the refining of shale oil.

Condensing the data in the last few pages into a flow sheet it appears that, tentatively, the best procedure to follow in the operation of an oil shale plant of any size in Kentucky is to use churn drilling, large blasts, steam shovel loading, gyratory and roll crushing with the elimination of dust, followed by retorting using steam, recovery of ammonia and topping the crude oil. The saleable products from such a plant would be motor fuel, fuel oil and ammonium sulphate, and the writer firmly believes that, given the proper conditions as to shale, plant site, retorting method used and management, a plant for the production of oil from shale is commercially feasible at the present time in Kentucky.

Conclusion

An analysis of the data given in the preceding pages shows that in every respect save possibly one, oil content, and this includes water, transportation, climate, labor supply, closeness to market and supply, cost of mining (ratio of one to three), method of mining, etc., the oil shales of Kentucky show a marked superiority over those of the western states from the standpoint of commercial operation. Such being the case, Kentucky is the logical place for the birth of the oil shale industry in the United States, an industry which, in its potentialities, staggers the imagination and one which the next few years should see obtaining a firm foothold in the industrial life of the Commonwealth of Kentucky.

IV.

SOME MOTHER PLANTS OF PETROLEUM IN THE DEVONIAN BLACK SHALES

David White and T. Stadnichenko[1]

General Description of the Material

In the course of the examination under the microscope of some of the richly bituminous shales from the older geological formations for the purpose of gaining information as to the source of the petroleums generated naturally or by artificial distillation from these shales, two types of plant fossils are found to be of unusual interest and economic importance. Both occur in black shales, regarded as of Genesee age, in northeastern Kentucky.

One of these plants is represented by forking divisions or thalli of a small seaweed, here named *Foerstia.* In the fronds of this plant the walls of the outer zone of cells are seen under the microscope to be thickly reinforced with reddish-brown matter, apparently of waxy-resinous composition. Overlying the surface of the plant is a pavement of translucent, lemon-yellow, waxy secretion, somewhat similar in composition to the reddish-brown underlying deposits, but rather sharply differentiated and clearly distinguishable chemically as well as by color. The small thalli, the cell structure of which is distinct and remarkably striking, as seen by transmittted light in the treated preparations, were evidently fortified against exposure to the air for considerable periods. The waxy or "waxy-resinous" protective secretions, which were especially designed to resist decay, render the bitumized and partially carbonized remains so tough and leathery that in some cases they may be lifted from the surface of the rock and subjected to experimental tests with solvents and reagents, as well as to study under lenses of moderate power. The superficial aspect of these minute thalli strongly suggests the scaly or semi-warty appearance of the common species of "rock weed" or *Fucus* of the Atlantic coast. The

[1] Published by permission of the Director of the U. S. Geological Survey.

Presented before Society of Economic Geologists, Ann Arbor Meeting, December, 1922.

PLATE I
Xoerstia ohioensis

PLATE I.

Foerstia ohioensis, n. sp., D. W.

Fig. 1. Natural size. Fragment of bifurcating thallus removed from matrix. Though treated in hydrofluoric acid at 50°-60° C., for 2 days, the specimen is still opaque. Fig. 1-a. Same specimen, × 2.

Fig. 2. Natural size. Fragments of thalli removed from matrix but still comparatively opaque, though subjected to alcohol for 2 days after treatment with hydrofluoric acid as before.

Fig. 3. Natural size. Pincer-shaped and fertile lobes. Details, enlarged, in Fig. 8.

Fig. 4. Oblong type of lobe still opaque, though removed from matrix. × 2.

Fig. 5. Natural size, shows incurved and overlapping ultimate lobes each suggesting bishop's crozier.

Fig. 5-a. Same specimen, × 2.

Fig. 5-b. Same specimen, × 22, to show leathery aspect of thallus, size and form of cutaneous cells, the external surfaces of which are decked with convex pavement of lemon-yellow waxy protective secretion.

Fig. 6. × 2, to show pincer-like form of division of thallus.

Fig. 7. Fertile bifurcating thalli at a. Small or young pincer type at b, at the right of which is fertile lobe. × 2.

Fig. 8. Showing pincer-like thallus at *a* with impression of another immediately on right. Numerous fragments of thalli in lower part. The pits on fertile lobe at *b* mark positions of the oogonia or conceptacles. × 2.

Fig. 9. Surface of lobe showing positions of oogonia, in 2 longitudinal rows in the leathery lobe. × 22.

Fig. 10. Natural size. Fragments of lobes, one, near middle, is elongated and bifurcating. This type is associated with the pincer and bishop's crozier forms, and may represent a species distinct from bifurcating type in figs. 1 and 2.

Figs. 3, 7, 8, and 10 from specimens, No. 4592, in the geological collections of Western Reserve University; kindly loaned by Prof. J. E. Hyde. All other specimens from the lower 100 feet of the Ohio shale near Vanceburg, Ky.

mode of occurrence of the egg cells or spores reminds one of the brown algæ. The secretion of fatty substances in the cells of some representatives of the latter class of plants is well known.

The other fossil that is of unusual interest from the petroleum standpoint is represented by innumerable small roundish spore sacks, now flattened and appearing as somewhat wrinkled or creased, irregularly rounded bodies, 3 to 5 mm. in diameter. These spore cases, the form and structure of which suggest their growth in the axils of leaves or bracts of some ancient relative of the modern Lycopods, are found under the microscope to have been provided with several outer layers of cells the walls of which, somewhat as in *Foerstia,* are provided with thick, russet-orange reinforcement of some waxy or, possibly, somewhat resinous substance. Likewise, the outer surface of the spore case is decked with a thin layer of extremely pale yellow or straw-colored waxy matter, highly refractive to light. The structure of the walls of these spore sacks is beautifully revealed in the preparations made by the junior author, but the inner tissues, not having been protected by decay-resistant secretions, have disappeared. That the fossils are sporangia of some Paleozoic plant is evident, though no spores have definitely been recognized in the interiors of the specimens here examined. From the structural characters and the evidence as to the mode of attachment, in which the fossils resemble certain spore cases of the Carboniferous *Sigillaria,* it is provisionally assumed that they belong to one of the Devonian types antecedent to the Carboniferous Lepidodendra and Sigillariæ. The fossils in hand are tentatively referred to the genus *Protosalvania,* for there is little doubt as to their generic identity with the carbonized plant remains from the Devonian of Brazil and Ohio, described by Dawson under that name. They can, however, bear only remote relation to the living *Salvinia.*

The evidence of the leathery, decay-resistant protective matter in *Foerstia* and *Protosalvinia,* pointing to the necessity of surviving periods unfavorable for living and the reproduction of their species, finds support in the waxy covering of the egg cells or spores of *Foerstia* even while enveloped in the mother thallus.

Both the algal thalli, *Foerstia,* and the spore sacs, *Protosalvinia,* are well adapted, on account of their size and preservation, to special micro-chemical study, in which the junior author has subjected the partially bituminized remains to a preliminary series of tests by various solvents and reagents to determine their probable original nature, some qualities of their present composition after having been changed more or less under geologic influences, and their behavior under solvents and heat treatment. These experiments show distinctly the chemical differentiation of the brown and yellow waxy or waxy-resinous deposits. The results of the micro-chemical studies, which are incomplete, are but briefly referred to in this paper, in which the chemical discussion is based on notes furnished by the junior author. The chemical experiments will probably be more fully described in a later publication following the continuation by her of this line of interesting, as well as profitable, investigation.[2]

The thalli of the alga *Foerstia,* though abundant at certain localities, do not appear to be so widespread as the spore cases, which have at places been found in very great numbers, completely covering the bedding planes of the shale and even accumulating in carbonized mats. Associated with both types, and, in fact, extremely widely distributed through the Devonian black shales and in the overlying shales now referred to the basal Carboniferous, are great numbers of resinoid or hard wax-like spore exines, referred to *Sporangites* by different authors, some of whom, notably Orton and Dawson, regarded them as the source of the Devonian oils of the northern Appalachian states. Both the *Sporangites* and the fossils here discussed under the name *Protosalvinia Ravenna* are certainly important sources of artificial oil obtained by distillation of the shale. Accordingly, their office in the generation of petroleum in the course of elapsed geologic time can not be doubted. As pointed out by Orton and Dawson, the *Sporangites* deposits are enormous in aggregate quantity in the black shales of Ohio, and in places

[2] The senior author is responsible for the introduction, the paleontology and geology of this preliminary report. For the chemical studies and their interpretation, as well as for the microscopical preparations he is indebted to the junior author, whose resourceful skill has also made possible the recognition in detail of the structural character of these fossils.

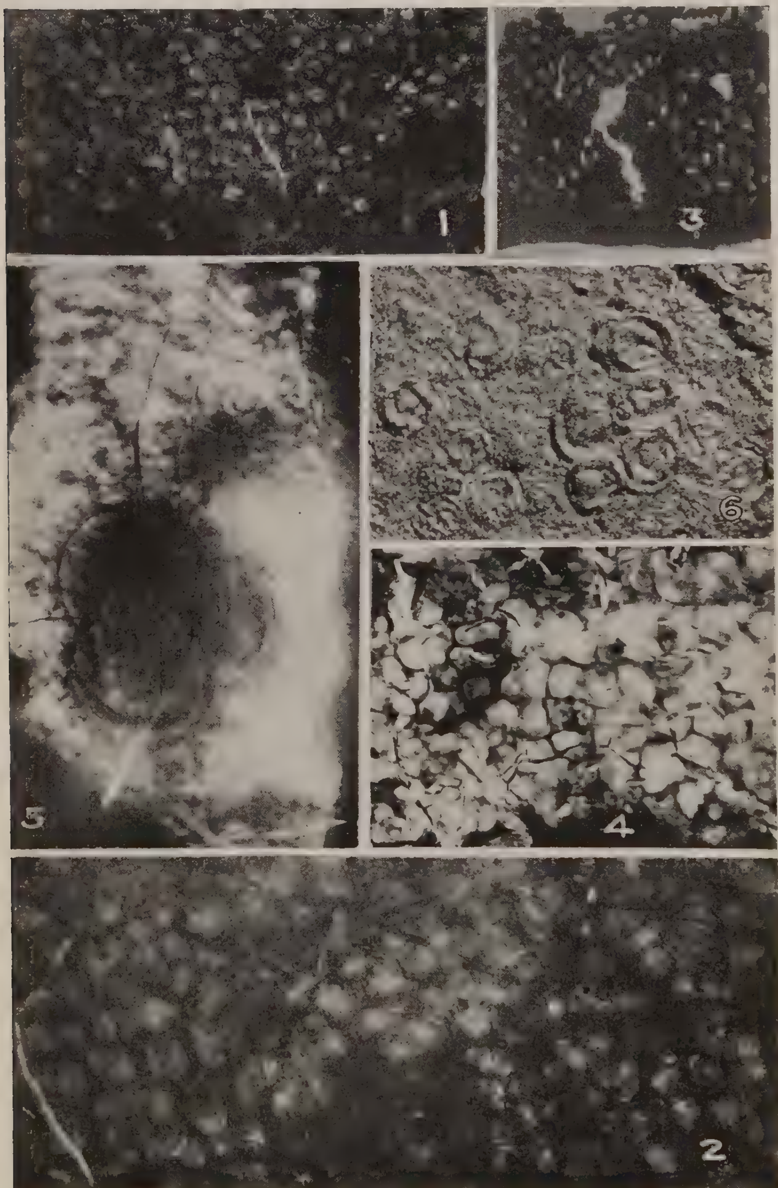

PLATE II.
Foerstia ohioensis and *Sporangites huronensis*

PLATE II.

Figs. 1-5. *Foerstia ohioensis*, n. sp., D. W. Fig. 6, *Sporangites huronensis*, Dawson?

Fig. 1. Wall of *Foerstia* thallus after treatment for 2 days in Schultz's reagent at 50°-60° C. Dense patches of humic or incompletely oxidized matter appear opaque. White spots mark points at which outer lemon-yellow cutaneous covering of the leathery thallus, shown in Fig. 5-b, Pl. I., is seen through the interiors of the subjacent reddish-brown-walled cells. × 40. Fig. 2. Same specimen, × 75. Shows several layers of subcutaneous cells of thallus wall. Traces of original cell laminae on left. White patches are views through to lemon-yellow cutaneous layer.

Fig. 3. Fragments of cell wall of *Foerstia* thallus from which, after preliminary treatment with Schultz's reagent, the lemon-yellow cutaneous decking has been dissolved by boiling 1 hour in pyridin, leaving only a reticular mesh residual from the reddish-brown thickening of the subcutaneous wall cells. × 25.

Fig. 4. Fragment of thallus wall which, after treatment with Schultz's reagent, was subjected for 5 minutes to a 2 per cent solution of KOH. After washing, the brown subcutaneous matter was removed, leaving only the lemon-yellow waxy cutaneous surface layer, here seen as a mosaic which indistinctly outlines the pattern of the subjacent cells. × 40.

Fig. 5. Portion of fertile *Foerstia* thallus, after treatment for 2 days with hydrofluoric and nitric acid. Four pale yellowish and slightly resinous or waxy-resinous egg cells are here seen nearly, if not exactly, in place, in the thallus though the wall of the inclosing oogonium has disappeared. The position and distribution of oogonia are shown in Figs. 9, 7 (a), and 8 (b) in Pl. I. Five groups of immature egg cells form a row on one side of the fragment of thallus, a portion of which is shown in Fig. 5. The cells of the thallus wall are obscurely indicated in upper left. × 90.

Fig. 6. *Sporangites huronensis* Dawson? Occurs in great abundance with several types of smaller spores, in lower part of the Ohio shale, in portions of which it completely covers the bedding planes. × 22.

Figs. 1 to 5 from the lower 100 feet of the Ohio shale near Vanceburg, Kentucky. Fig. 6 from same stage at Ravenna, Ky.

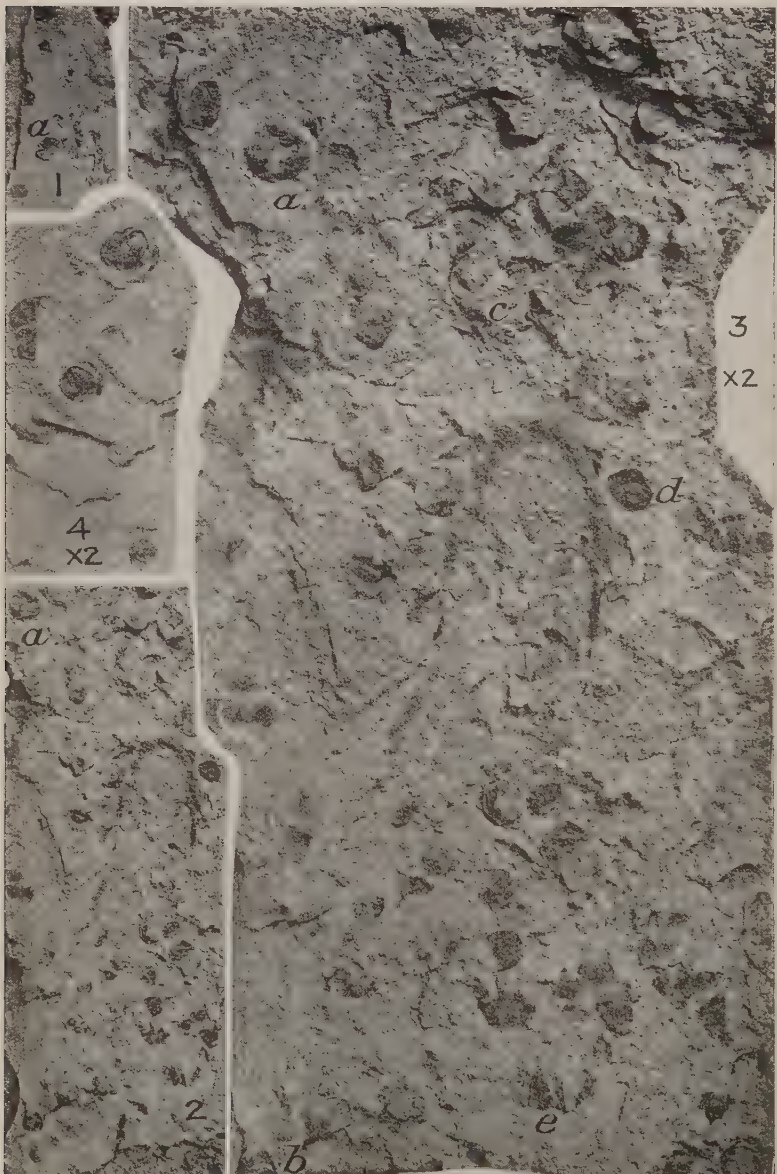

PLATE III.
Protosalvina Ravenna

PLATE III.

Protosalvina Ravenna, n. sp., D. W.

Fig. 1. Natural size. Flattened sporangia on small fragments of gray shale. Specimen marked a is shown enlarged in Pl. III., Fig. 2.

Fig. 2. Natural size. Shale with numerous sporangia; matted in part of specimen. They are thinner and less leathery than the thalli of *Foerstia.*

Fig. 3. Portion of specimen of Fig. 2, $\times$ 2. a. Sporangium with tetrad aspect, but indentation toward the right is axial, the cushions above and below it being lateral, as shown in Pl. V., Fig. 1. c. shows axial features and rupture, the latter illustrated more clearly in b, d, and e.

Fig. 4. Collapsed and wrinkled sporangia with rupture of large specimen on left. $\times$ 2.

All specimens from basal portion of Ohio shale at Ravenna, Ky.

are so concentrated as to compose beds from a few centimeters to several feet in thickness and so fatty with the organic matter as to be readily lighted with a candle. The *Sporangites,* which appear to be the decay-resistant walls (exines) of some type of megaspores, possibly of Lycopod affinity, are undoubtedly somewhat different in composition from the plant secretions found in the walls and coatings of *Protosalvinia* and *Foerstia.* All of these plant products especially resistant to decay were originally and are at the present moment characteristically high in hydrogen, and, like the wax-resin series, relatively low in oxygen. Failure to respond to ordinary resin and wax solvents without preliminary treatment is due to alteration, or, as it is called, bituminization. They are by chemical composition particularly adapted to the generation of the hydrogen-rich hydrocarbons, namely, the petroleums, and this is shown by the high grade of the oil obtained from them by distillation. They are, in fact, related in composition to the rich algal coals or so-called bogheads which are paramount in interest, if not importance, as mother rocks from which distillates approaching most nearly the present types of natural petroleum may be obtained.

In addition to the more readily visible and more easily studied bituminized remains of plants found fossil in these shales, there is evidence, here and there, of large amounts of more or less fibrous or spongy plant material of waxy or resinous aspect, in which no cell structure has yet been clearly seen. This material, which was certainly deposited at the time the beds were laid down and can not be explained as any impregnation of the strata by waxy hydrocarbons, is likely to belong to some of the lower orders of plants, probably algæ, and it may ultimately be found to have been even more dominant as a source of petroleum than the easily recognized and abundant *Sporangites* spores or the *Protosalvinia* spore-containers. It is hoped that in the course of further study of these shales more may be learned as to the origin, structure, and composition of these more baffling plant residues. In this connection it is germane to mention a tentative conclusion reached by the late C. A. Davis in the course of his study of the oil shales of the Green River formation, on which he was engaged at the time of his death, namely, that an extremely delicately filamentous alga-like plant, growing in

felt-like meshes to form carpet-like layers, most difficult of structural differentiation and identification, was perhaps the principal source of the oil in the shales of the Green River formation.

Besides adding two types to the list of plants pre-eminently adapted to the generation of petroleum in the Devonian shales, these studies furnish new criteria both for the micro-paleontological identification by the driller of a stage in the black shale series of the region and for the general purpose of stratigraphic correlation between regions. It is hoped that the success met in the micro-chemical treatment of the material in hand will stimulate a more widespread study of the thin and even minute carbonaceous plant residues so common in the rocks of the Devonian and other periods.

Geologic Stage and Localities of the Fossils

The plants described as *Foerstia ohioensis* are found in great abundance in interbedded gray and blackish shales in the lower part of the Ohio shale in the bluff of a creek half a mile southwest of Vanceburg, Kentucky. This shale is of Upper Devonian age and has been referred to the Genesee. *Sporangites* is present in great numbers, but it is also widely distributed throughout the entire black shale group.

The specimens of *Protosalvinia Ravenna* here illustrated are from the gray and black shales overlying the limestone locally called Irvine "sand" (of probable Onondaga age) in the shaft sunk for oil development on the hillside at Ravenna, 2 miles east of Irvine, Kentucky. These specimens bear the lot number 88-A. The same species are found in the railroad cuts along the river, 2 miles west of Irvine; in the lower part of the black shale and in the grayish layers immediately overlying the Irvine "sand" north of Junction City, Kentucky, and in the basal portion of the black shale in the quarries of the Devon Shale Oil Company on the north river bank, 2 miles northwest of Clay City, Kentucky. At all these localities the fossils are in the lower portion of the Ohio shale.

Notes on the Micro-Chemical Experiments

On account of the differences in the functions of the plant parts and on account of the difference between the classes of

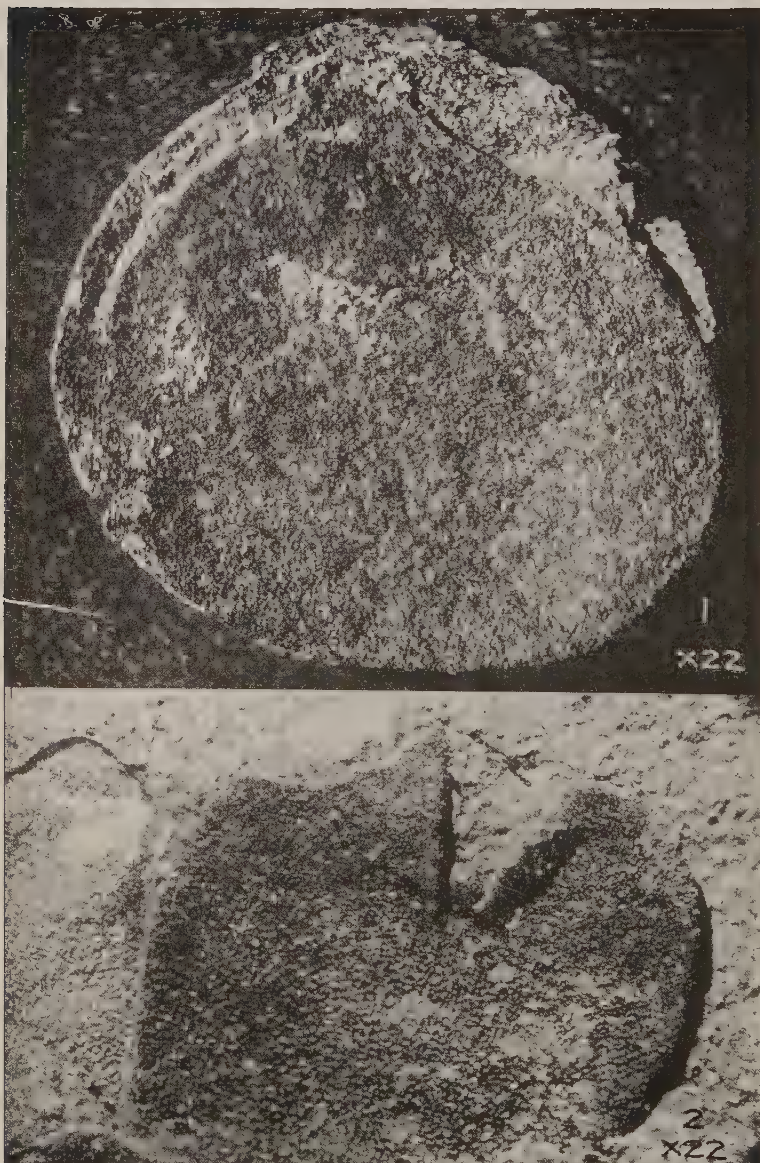

PLATE IV.
Protosalvinia Ravenna

PLATE IV.

Protosalvinia Ravenna, n. sp., D. W.

Fig. 1. Collapsed sporangium detached from matrix and photographed without treatment. Wrinkling seen in upper part and axial sinus faintly indicated to upper left of center. $\times$ 22.

Fig. 2. Axial depression, appearing V-shaped by accident of compression. Lateral lobes, with small thick-walled cells, seen on either side, grading into larger cells, in lower part of photograph. Portions of underlapping sporangia at left, and overlapping, at extreme lower left. $\times$ 22.

The convex surface of the epidermal cells decked with cutaneous waxy refractive matter, suggesting cobble-stone pavement, is well shown in lower part of figure.

Specimens from near base of Ohio shale at Ravenna, Ky.

the plants represented by the remains in hand, as well as on the basis of the mode of occurrence of the preservative secretions as cuticular surface coverings or as reinforcement of the walls of the subcutaneous cells, it was at the outset assumed that the special decay-resistant plant substances were probably allied in composition to the waxes or resin-wax group. Accordingly, reagents and solvents were for the most part used with this hypothesis in view. The following incomplete notes are preliminary, as further studies of this and other related materials are in progress.

In *Foerstia* all the specimens were opaque before treatment, as also were all but the thinest fragments scaled from the sporangia of *Protosalvinia.* Both appear carbonized, especially *Protosalvinia.* Untreated *Foerstia* is more leathery in aspect and is, in fact, tougher and less subject to splitting when first gathered. *Protosalvinia* is wrinkled and looks more "dried out." It is important to note that none of the material responded to the solvents used (alcohol, ester, chloroform, carbon tetrachloride, carbon bisulphide, pyridine) even at boiling temperatures for considerable time unless the specimens had been previously treated with oxidizing reagents. However, *Protosalvinia*, after treatment three days with strong hydrofluoric acid at 50°-60° C., was slightly attacked by alcohol, which, after boiling an hour. was stained a little at the expense of the brown matter. Similar slight staining resulted from the substitution of chloroform in place of alcohol. Practically no effect was noted when, after treating with HFl as above, *Protosalvinia* was subjected to KOH (50 per cent.) for two hours at room temperature. It is to be inferred, therefore, that the organic plant material has been "bituminized." Both in the clarification of the plant fragments and in the chemical experiments beneficial results were obtained from the use of hydrofluoric acid, which not only assists through removal of the inorganic matter, but seems also to exert a favorable influence on the reactions.

Solution in varying degrees, and with evident selective differentiation, was observed when, after preliminary treatment with HFl, the plant fragments were subjected either to HNO_3 or Schultz's reagent[3] before they were placed in the solvent.

[3] 10 HNO_3 (1:1) and 3 $KClO_3$.

Schultz's reagent is the more drastic and rapid in its action. Both the nitric acid and Schultz's reagent are useful in rendering the specimens more transparent, probably due in part to the removal of "humic" matter, in advance of any application of solvents. In fact, portions of the specimens may be successfully studied under the microscope without further preparation. Neither of these two oxidants appears to attack the cutaneous yellow plant secretion, but the brown cell-wall thickening, when washed promptly, seems somewhat reduced as well as more translucent. After treatment for two days with HFl and HNO_3 in equal parts at 50°-60° C., *Foerstia* was found to have been more strongly affected than *Protosalvinia*. Similar specimens, treated as above, or with Schultz's reagent following HFl, for the same period, were energetically, and almost instantly, attacked by a 2 per cent solution of KOH, which rapidly darkened while the brown matter was wholly removed as is illustrated in Fig. 4, Plate II, with slight effect on the yellow matter, though with prolonged subjection to KOH the yellow deposit also eventually disappears. The cell remains are much swollen in the caustic potash prior to dehydration.

Some results of the action of solvents may be briefly noted. The action of solvents on specimens of *Foerstia,* which, in each instance, had first been treated with HFl for two days, followed by two days on Schultz's reagent, all at 50°-60° C., is as follows: Boiled in C_2H_5OH for 1 hour, the brown matter and the yellow are somewhat reduced and the cells dilated. Boiled in $CHCl_3$, reduction of brown and yellow matter is noted. Carbon bisulphide and CCl_4 applied at boiling temperatures for 1 hour do not have visible action on *Foerstia*. After subjection to pyridine at 100° for an hour, the yellow matter is taken out and the brown is shrunken and generally darker, as shown in Fig. 3, Plate II.

Sporangia of *Protosalvinia*, after treatment with HFl and HNO_3 in equal parts, at 50°-60° C., for 3 days, were submitted to solvents with the following results: CS_2 for an hour, and CCl_4 for two days, at boiling temperature, had no visible effect, thus agreeing with the tests of *Foerstia*. Boiling in alcohol 10 minutes removes the yellow matter, while the brown, much shrunken, appears grayish, losing its warm red tone. Pyridine even for 3 hours at the boiling point does not act so strongly on

PLATE V.
Protosalvinia Ravenna

PLATE V.

Protosalvinia Ravenna, n. sp., D. W.

Fig. 1. Basal or axial portion of sporangium showing lateral cushions, rings," in effect, with, small cells on either side, and portion of wall with large cells on opposite side of spore sac. Treated in HFl and HNO_3 (50 per cent + 50 per cent) for 3 days at room temperature, followed by boiling 3 hours in pyridin. Portions of sporangium are still opaque, especially where both walls are cemented in contact. On upper right, below folded border, a thin strip has split off showing in single layer large outer cells of the opposite wall which projects beyond the broken edge of the smaller-celled, near wall of the lateral cushion. × 25.

Fig. 2. × 25, to show mesh of cells with walls thickened with russet-brown matter. Treated for 3 days in hydrofluoric acid at 50°-60° C., followed by KOH (50 per cent) for 2 hours, which has removed most of the humic matter and has somewhat reduced the brown deposit. The cutaneous covering of straw-colored waxy matter appears as white patches seen through the subjacent brown walled cells.

Fig. 3. Portion of Fig. 2, × 240, to show the russet-brown thickening of the lateral walls of the outer zone of cells, which are here seen to be at least 3 deep. The original cell laminae are faintly seen, while the outer, cutaneous, waxy pavement shows white, as seen through the interiors of the cells of wall. The specimen represents the remains of one wall only of the sporangium.

Fig. 4. Fragment of sporangium wall, × 25. This specimen, after treatment with mixed hydrofluoric and nitric acid, was boiled for 10 minutes in alcohol which has dissolved and removed the lemon-yellow cutaneous or suface deposit, as well as a portion of the brownish cells of the underlying walls, the remains of which are here seen as a reticulate mesh. The white patches are openings where formerly lay the waxy cutaneous decking seen in Pl. IV., Fig. 2.

From near base of the Ohio shale, Ravenna, Kentucky.

Protosalvinia as on *Foerstia,* and is limited to some reduction of the yellow in the thinnest parts, while ester appears to cause both reduction of the yellow and the brown matter and swelling.

The foregoing experiments clearly show that both in *Foerstia* and in *Protosalvinia* the brown preservative material of the cell walls differs chemically, as well as optically, from the yellow surface decking. The experiments are interpreted as indicating also not only that the brown matter of the one differs chemically somewhat from that of the other, but that the yellow cutaneous deposit differs in the two plants. Thus, boiling in alcohol removes the yellow matter from oxidized *Protosalvinia* within 10 minutes, while in *Foerstia,* after an hour the yellow substance is changed but slightly. Pyridine, which removes the yellow in *Foerstia,* has not so strong an effect on *Protosalvinia.* This accords with the natural assumptions based upon biological probabilities, since it is practically certain that neither the brown decay-resistant substance of the thickening of the cell walls, nor the yellow cuticular surficial deposit of the alga, had the same original chemical composition as the similarly deposited brown and yellow secretions of the sporangium wall of a much higher order of plants, possibly related to the Lycopods. The results of the experiments already made indicate compositions in the yellow more nearly related to the waxes, while the brown deposits on the walls of the sub-cutaneous cells may be presumed to represent compounds somewhat resinous or waxy-resinous in nature. The brown material in *Foerstia* probably has its closely related plant product in some of the living algæ from which it presumably differs in composition to correspond to its greater resistance to decay.

Mother Sources of Oil in the Black Shales

The results of this examination show that, in addition to the resinous or waxy-resinous spore exines of different species known as *Sporangites* that occur so widespread and locally in innumerable numbers in the black shales of the Devonian and basal Mississippian, we have at least two types of larger and more complex plant growth locally in the greatest abundance that, according to the micro-chemical indications, are especially suited to serve as ideal mother substances from which to generate artificial

petroleum of high grade, and that beyond reasonable question have been important contributors to natural Appalachian oils. The chemical tests in progress by the junior author, though incomplete, are sufficient to show a variation in the composition of these plant substances that may be as important in determining the character of the oils as they are interesting to the paleontologist and stratigrapher. Obviously in these remains of plants of different orders we have vast amounts of somewhat bituminized and characteristically high hydrogenous plant material, which probably varies also both in fusing temperatures and in temperatures of distillation. It is reasonable, therefore, to conclude that the detailed micro-chemical and micro-thermal study of these fossil remains will throw great light, not only upon the origin of petroleum in general in the Devonian of the Appalachian trough, but upon the original sources—*i. e.,* the fossil plant products and remains responsible for the different characters and qualities of the distillates initially. These ingredient products, by their different compositions and properties, should account also, to some extent at least, not only for the variation in the distillates obtained in the same retort and under identical treatment from different shales, but also for the varying temperatures at which the same rocks give distillations of different types.

U. S. Geological Survey,
Washington, D. C.

V.

GEOLOGY OF WOODFORD COUNTY

By Arthur M. Miller

Assistant Geologist

Woodford County, named after General William Woodford, a Revolutionary officer, was organized from Fayette County in 1788, being the eighth and next to the last county constituted while Kentucky was yet a part of Virginia. As first formed it included all that portion of the original Fayette, after Bourbon had been separated from it, which was bounded by the Ohio from the mouth of the Licking to the mouth of the Kentucky, thence up the latter to one and one-half miles above "Todd's Ferry," thence by a straight line (present boundary between Woodford and Jessamine, Woodford and Fayette, and a portion of Scott and Fayette) to the crossing of the "Leestown road at the eight mile tree," thence by "a straight line (present continued boundary between Scott and Fayette) to the watershed between the waters of Licking and waters of Kentucky, thence by this watershed (present boundary between Scott and Bourbon and Scott and Harrison in part) to the head of Eagle Creek, thence by a straight line to the nearest part of Raven Creek, thence down this creek to the mouth, thence down the Licking to the point of beginning on the Ohio."

In 1792 the county was reduced by setting off from it the original Scott County, which was made to include all that portion bounded by a line "commencing where the straight line beginning on the Kentucky river one and one-half miles above Todd's Ferry and drawn to the eight mile tree on the Leestown road crossed the Town Fork of South Elkhorn Creek, thence down this fork to the mouth, thence down South Elkhorn so far that a line drawn north 20 degrees west will strike the eight mile tree on the road leading from Frankfort to Georgetown, thence a straight line to intersect the big Buffalo road between the head of Cedar Creek and LeCompte's Run, thence a straight line to the Ohio river at the mouth of Big Bone Lick Creek, thence up the Ohio to the mouth of the Licking,

thence up the Licking to the mouth of Raven Creek, thence up Raven Creek and across to watershed between the Licking and the Kentucky, thence along the watershed to where intersected by the Fayette line, and thence with this line to the point of beginning."

The county received its present form and size when the original Franklin County was set off in 1794 from Woodford, Mercer and Shelby counties. The part cut off from Woodford was determined by drawing a straight line from the point on South Elkhorn Creek, which was 20 degrees east of south from the eight mile tree on the Frankfort-Georgetown road, so as to strike the Kentucky river one mile above the mouth of Glenn Creek. Following this date all that part of Woodford which had lain north of this line became Franklin County.

Woodford County as it was then constituted, and still remains, contains 189.8 square miles. It has its greatest length—23.75 miles—from north to south and its greatest breadth—13 miles—from east to west. In shape it is something like Kentucky in miniature. It has 65 miles of stream boundary (40½ miles of Kentucky river and 24½ miles of South Elkhorn Creek). It is bounded on the north by Franklin and Scott, on the east by Fayette and Jessamine, on the south by Mercer, and on the west by Mercer and Anderson. In 1920 it had a population of 11,784, a decrease of 787 from that of the preceding census and 1,350 from the census of 1900.

Towns, Railroads and Pikes

There are three incorporated towns in the county: Versailles, the county seat, established in 1792, at the big spring at the head of Glenn Creek, had a population, according to the last census, of 2,061, which was 207 less than in 1910, and 276 less than in 1900. Midway, about half way between Lexington and Frankfort (hence the name), on the Louisville and Nashville, and Versailles and Georgetown railroads, was incorporated in 1846. It had, according to the last census, a population of 915, which was 22 less than in 1910, and 130 less than in 1900.

Mortonsville, five miles south of Versailles, was incorporated in 1835, but is not now listed in the census report as an incorporated town. Three railroads traverse the county: the

Louisville and Nashville, over which the Chesapeake and Ohio trains also run, crosses the northern portion of the county from east to west, the Louisville Southern passing through Versailles, crosses from east to west the middle portion, the Louisville and Atlantic (L. & N. system) crosses diagonally from southeast to northwest, passing through Versailles, and the Versailles and Georgetown railroad (Southern system) runs northward from Versailles, through Midway to Georgetown.

Seven pikes radiate from Versailles; the Versailles-Frankfort, northwestward; the Versailles-Lexington, eastward, both being a part of the Midland Trail; the Mt. Vernon (Big Sink) northeastward to intersect the old Frankfort pike; the Nicholasville, to the south, which about a mile from town gives off a fork to the east, known as the Dry Ridge pike; the McCowan's Ferry to the southwest; the Shryock's Ferry or Lawrenceburg pike to the southwest; the Clifton to the northwest, and the Glenn Creek or McCracken to the northwest. The Frankfort pike forks about a mile northwest of town, the right-hand leading to Midway and Georgetown. Two main pikes, the old Frankfort and the Leestown, traverse the northern end of the county from east to west. There are a number of other cross pikes, which with the main pikes, render all parts of the county easy of access.

Early White Settlement

The earliest white settler in the county, as at present constituted, appears to have been Capain Elijah Craig, who, according to Richard H. Collins in his History of Kentucky, built in the winter of 1782-83 a "station" at a point which is now "about five miles from Versailles and ten miles from Lexington." The exact spot where this station was located does not now seem to be known, but there is some probability that it is the "Summer Forest Place," located on the Dry Ridge pike five miles from Versailles and ten miles from Lexington. On this place, and incorporated in the present residence, is a very old stone house with very thick walls which was there when the place was purchased in 1795 from Thomas E. Sumner, devisee of General Jethro Sumner, who had as an officer in the Revolution received a grant of 2,000 acres located in this portion of Woodford and neighboring portions of Fayette and Jessamine. The

place was purchased by John Brown, first Senator from Kentucky, as a home for his parents. His father, "Parson" John Brown, was the first pastor of Pisgah church in the eastern part of the county, and his brother, Dr. Samuel Brown, was the founder of the medical college of old Transylvania University in Lexington.

Other early settlers, mentioned in the History of Kentucky, written in 1847 by Judge Lewis Collins and revised in 1874 by his son, Richard D., were Major Herman Bowmar, sen., General Charles Scott, Colonel John Crittenden (father of John J. Crittenden), Colonel Thomas Marshall, General James McConnell, Colonel William Steele, Benjamin Berry, Lewis Sublett, Edmund Woolridge, Henry Watkins, and one or more families of Moss, Wilcox, Holeman, Stephenson, Craig and Slaughter. The old home of General Charles Scott, afterwards Governor of Kentucky, a stone structure overlooking the Kentucky river in the southern part of the county, still stands. The old Crittenden homestead is about a mile east of Versailles and to the north of Lexington-Versailles pike. The old Marshall homestead, "Buck Pond," adjoins this to the east. It was purchased in 1783 by Colonel Thomas Marshall, father of several distinguished sons, one of whom was Chief Justice John Marshall, of Virginia. Buck Pond passed from Colonel Thomas to his son, Dr. Louis (born 1773, died 1863), and is still in possession of a Marshall descendant (Louis Marshall).† To the above pioneers must be added the Blackburn family, which settled near Versailles, families of Blacks, Guyns and Pauls, who settled on upper Clear Creek, and Jacob Frohman, who settled on Brush Creek in that portion of the county known as Clover Bottom. Jacob Frohman, a German, is credited by Collins to Mercer County, and it is true that he appears to have represented that county in 1792 in the convention called to establish the first State Constitution and in the first meeting of the legislature authorized by it. But we find that at a date certainly as early as this he had settled at the head of Brush Creek and had there built a stone house over a spring so that the Indians could not cut him off from water in case of attack. Later he built a finer stone house upon the hill overlooking the spring, and lower down on the

† Deceased since the writing of this report.

creek a mill. All these structures were built of Tyrone limestone. The early "spring house" and the mill are in ruins, but the house upon the hill is still in an excellent state of preservation and serves as a residence for the present owners of this portion of the old Frohman estate. Descendants of the original Jacob Frohman still live on a remaining portion of the estate.

Also the Guyns and Pauls built, of this white Tyrone limestone, homes and mills (the latter generally with distilleries attached). The earlier of these mills and distilleries may still be seen as picturesque ruins on upper Clear Creek. The old Paul distillery may have been built originally with a view to defense against the Indians, as its walls are perforated at intervals with loop-hole-like openings such as the pioneers made in the sides of their homes and forts in order to permit rifle fire from within.

Another early settler was a Scotchman, Robert Alexander, sen., who settled near what is now Spring Station in the northern part of the county, purchasing there, in 1790 or 1792, what afterwards under his sons, Robert and John, became the celebrated "Alexander estate," known as "Woodburn." Robert Alexander, jun., was born in Woodford, but returned to Scotland to live with his titled uncle, a wealthy iron smelter, who made Robert, jun., his heir. The deposit of iron having been exhausted at Airdrie, Scotland, Robert, after the death of his uncle, returned in 1851 to Kentucky and tried for a time unsuccessfully to manufacture iron in Muhlenberg County at a place he christened "Airdrie," after the old home place in Scotland. After the failure of this enterprise he came back to Woodford County, bought back a large portion of the original estate of his grandfather, and lived there until his death in 1867. Another pioneer family was the Garnetts, descendants of whom live near Fort Garnett, in the vicinity of Pinckard.

Archaeology

Traces of several prehistoric earthworks have been found which bear testimony of the former Indian settlement of the county. They are mostly of such nature as to indicate that they mark the sites of defensive structures. One of these is on both sides of South Elkhorn Creek at the mouth of Steele Run. This was described and figured by Constantine Rafinesque in one of his unpublished manuscripts written about 1820. The plat of

the earthworks was reproduced in the first Smithsonian Report, vol. 1, 1848, credit being given to the author. It also appears in Collins' History of Kentucky on the plate between pages 68 and 69, vol. 2, where without giving credit for the source it is erroneously located in Bourbon County. At the time it was described by Rafinesque it consisted of a low ridge of earth in the form of an irregular circle which enclosed about 15½ acres lying on the west side of in a big bend of South Elkhorn Creek, and extending across to the east side just above the mouth of Steele Run. Not a trace of this earthwork now remains.

Photograph by A. M. Miller

"OLD FORT PLACE"

This is the old Shipp residence. It is entirely surrounded by an Indian earthwork, a portion of which may be seen at the left.

Another earthwork figured and described by Rafinesque in the manuscript to which reference has been made and reproduced in the first Smithsonian Report and in Collins' History, vol. 2, page 765 (in the latter without giving credit to the source), is on the present Sunny Slope farm, owned by J. B. Shipp and Son, an estate which adjoins Woodburn on the east. This was formerly known as the "Fort Place," because the residence built by the original owner, Richard Doniphon Shipp, was located inside the earthwork. The residence was certainly built before 1820. As described by Rafinesque, the earthwork was octagonal in form with each side 150 feet in length and 6 feet high. It had two entrances on the north side at two of the

angles of the octagon, and one in the middle of the west side. There were two mounds within the inclosure on the south and east sides. Nothing octagonal in shape can now be discerned in this earthwork. and no signs of any entrances or mounds. It is now traceable as an irregular circle. The present owner, who can remember as far back as 1875, never heard of its being octagonal in form, or of there being any entrances or mounds.

A third of these earthworks is located on the farm of Edwin Craig, 7½ miles southwest of Versailles on the McCowan's Ferry pike. It stretches across from cliff to cliff so as with the cliffs to enclose a point of land between the Kentucky river and Hall's Branch. It is a low ridge about 6 feet high and 300 feet long composed of earth and loose stones.

We now know that these prehistoric low ridges of earth, or of earth and stone, always about the same height, were thrown up to buttress the wooden palisades enclosing Indian villages or places of Indian refuge, which palisades were designed to make the areas enclosed impregnable against attack. In the case of the one just described on the Craig place, the rest of the enclosure was formed by a precipitous cliff which could not be readily scaled.

There are known to have been two Indian mounds in the county, one near Spring Station, now razed to the general level, and the other on the Sumner Forest place.

Topography and Drainage

Like its sister counties of the Inner Blue Grass region. Woodford consists for the greater part of a gently rolling upland. The vertical range is from 483 feet to a little more than 1,000 feet above sea level. The former elevation is on the Kentucky river near the mouth of Glenn Creek, and the latter is found on two of the highest hills between the Dry Ridge pike and the Louisville and Atlantic railroad, about 2½ miles southeast of Versailles.

The principal streams of the county flow westward and northwestward into the Kentucky river and northward into South Elkhorn Creek. The former, named in order from south to north, are Clear, Craig's, Grier's and Glenn, and the latter, named from east to west, are Sinking Creek and Beale's Run.

All, except Clear Creek, have their entire courses within the county. One branch of Clear Creek rises in Jessamine County. All these streams flow into the Kentucky river at grade, and have, therefore, of necessity, cut deep valleys in their lower courses. These are progressively more gorge-like in character in passing successively from Glenn Creek to Clear Creek, because the rising of the formations from north to south has caused the more southerly streams to cut more deeply into the cliff-forming rocks of the Highbridge series.

Much of the drainage of the eastern half of the northern portion of the county is underground. The courses of these underground streams may in many instances be traced by lines of sinks which appear upon the surface. Where the streams emerge they form "big springs" such as the town spring at Versailles (reason for the establishment of the town there), and the one near Spring Station.

The Kentucky river in its winding course of 40½ miles along the southern and western boundary had originally an average fall of less than a foot to the mile. Since the locking and damming of the river this fall is now concentrated almost entirely at the two locks located in this stretch. The lower one of these, No. 5, is a little above the village of Clifton, and the upper one, No. 6, is a short distance below the Oregon ferry.

Stratigraphic and Areal Geology*

The solid rock formations of the county, which would all classify as limestone, lie on the western and northwestern flank of the "Jessamine Dome" (see Geology of Jessamine County). The stratigraphic range—about 600 feet—is limited to the lower and middle part of the Ordovician (Champlainian and lower Cincinnatian). This exposure of 600 feet of rock within an altitude range of about 525 feet is made possible by a dip to the northwest and west at from 10 to 20 feet per mile. Measurements made on the stromatocerium reef at the top of the Benson bed indicate that from the highest level at which it is found (about 920 A. T.) in the region of the intersection of the Military and Pinkard pikes, the dip is a little north of west at the rate of between 15 and 20 feet per mile. Measured on the top of the

*Detailed geological map of Woodford County, Ky., by Prof. A. M. Miller, scale 1 in. = 1 mile, is available. Price 25 cents, from office of the Kentucky Geological Survey.

Tyrone limestone along Clear Creek the dip is down stream in a westerly direction at about 18 feet per mile. The subdivisions of the solid rock formations in the county with their thickness and outcrop areas are given in the following table:

Series	Stage	Sub-stage		Thickness in Feet.	Areal Outcrop in Sq. Miles
Cincinnatian	Eden	Million		50	.70
	Cynthiana	Greendale		40	9.15
Champlainian	Lexington (Trenton)	Perryville	Salvisa	0— 5	4.93
			Faulconer	0—10	
		Bigby	Woodburn	40	71.51
			Brannon	15	17.52
			Benson	75	
		Jessamine		80	
		Hermitage		35	73.29
		Curdsville		20	
	Highbridge (Stones River, Black River, Chazy)	Tyrone		90	
		Oregon		30	12.72
		Camp Nelson		130	
		Total		620	189.82

High Bridge Stage

Camp Nelson Bed. Dipping down the Kentucky River steeper than the fall of the stream, this formation from an exposed thickness of 285 feet at Camp Nelson, from which locality it receives its name, has as it enters the county with the river

from Jessamine a thickness of 130 feet. At lock No. 6 the top of the formation is but a few feet above the level of the river just below the dam, and from there to a short distance below lock No. 5, where it finally disappears from view, its top is in some places below and in others a slight distance above river level. The formation is exposed for short distances up to the main tributaries entering the Kentucky in this stretch, reaching in the case of Clear Creek as far as the crossing of the pike between Mortonsville and Nonesuch (Cumming's Ferry pike). From deep well drillings in this and neighboring counties the formation is known to underlie this central Blue Grass region with a thickness of about 440 feet. Below it lies a great thickness (2,-330 feet) of magnesian and sandy limestones belonging to the Knox dolomite series. The sandy beds were formerly identified as St. Peter sandstone, and sometimes called the "Calciferous." It is in this formation at the Old Crow distillery at a depth of 777½ feet that a fine supply of sulphur water was struck which flows under artesian pressure. The exact horizon at which this flow was struck was about 252 feet below the top of the Knox dolomite.

The Camp Nelson is a massive bedded limestone light to dark colored, and mottled in the interior, the mottling being due to streaks of magnesium limestone through it, which appear to be replacement of algal fronds and stems. It is fine grained and breaks with a conchoidal fracture. Certain layers in the vicinity of Mundy's Landing are finely banded parallel with the bedding. The mottled layers on weathering present on the edges a honeycomb appearance. This is due to unequal weathering of the magnesian and the purer limestone portions.

Being quite hard and resistant to weathering it forms precipitous cliffs where trenched by the Kentucky river and its tributaries. As it does not extend out into the uplands it has formed virtually no soil areas. Fossils are not abundant. The same ones may be found in the Woodford exposures as in those of Jessamine, where the greatest area of outcrop occurs. To be looked for among these are the gastropods, *Macluria bigsbyi*, *Lophospira perangulata*, the brachipods *Scenidium anthonense*, *Rafinesquina minnesotensis;* very large cephalopods belonging to the genera *Endoceras, Ormoceras* and *Actinoceras;* the bryozoa

Rhinidictya trentonensis, and *Phylloporina sublaxa;* and the ostracod crustacean *Leperditia fabulites.* Faunally and lithologically it correlates with the Stone's River of Tennessee and the Chazy of New York.

Photograph by A. M. Miller

DETAIL OF THE PHOSPHATE QUARRY

Modern open pit and quarry methods are used in this operation.

The Oregon Bed. Named from exposures in the vicinity of lock No. 6, near the village of Oregon in Mercer County. It is here 27 to 30 feet thick with the top 34 feet above pool level. The most conspicuous feature of this bed is its magnesian layers, some of which are quite thick and afford good dimension stone, and in some cases have been used in lock construction (lock No. 5). The dressed stone in lock No. 6, however, came from Bedford, Indiana, the fine layers of the Oregon right at hand being used only in broken pieces for riprapping. The magnesian content varies in the Oregon bed from small amounts to as much as 33 per cent. In the larger amounts it gives a cream color to the stone, and a "mat" surface on fresh fracture. The fracture is conchoidal. Fossils are rare and do not differ much from those of the Camp Nelson. The stone from this bed is variable in its weathering qualities when taken from different outcrops. Some of it affords a very fine building stone.

Its area of outcrop follows pretty closely that of the Camp Nelson and for mapping purposes it has not been found convenient to separate the two.

The Tyrone Bed. This formation, the "Birdseye" of William Linney, was rechristened with its present name by the writer in 1905 from a place of typical outcrop, Tyrone, on the Anderson side of the Kentucky river on the pike from Versailles to Lawrenceburg, and on the Louisville Southern railroad at Young's High Bridge. Its bottom is here close to river level and its top about 90 feet above. It is a fine-grained, dove-colored limestone, weathering white on exposure to the air. It breaks with a conchoidal fracture, exhibiting on the curved surfaces glistening facets of calcite (hence the name "Birdseye"). The calcite mineral has filled tubes through the rock which appear to have been casts of algal stems, and the limestone itself appears to have been formed from lime secreting marine algae. Near the top of the formation (about 18 feet below the top) there is commonly a bed of clay of peculiar composition, described in Report on Jessamine County as well shown at High Bridge. This has recently been identified by the U. S. Geological Survey as "Bentonite" and interpreted as an old volcanic ash. Immediately underneath it is usually a ripple marked surface which has undergone silicification, probably from the silica of the overlying bentonite, and there are further evidences toward the top of the formation in ripple marks and sun cracks, that this portion of the sea bottom toward the close of Tyrone time was emerging above sea level. Fossils are not common in this formation. As characteristic may be mentioned a problematic form, *Tetradium fibratum*, the bryozoan *Phyllodictya frondosa*, the gastropod, *Helicotoma verticalis*, and the ostracod crustacean *Leperditia fabulites.*

The stone possesses qualities which render it fine for building purposes, and many of the old structures in this county, such as mills, distilleries and the homes of the pioneers along the river, and on Clear, Craig's and Greer's Creeks, were built of it and remain today in a good state of preservation. It also furnishes excellent material for road building and for agricultural purposes. For the latter use it is extensively quarried and crushed.

Trenton Stage

Thickness (average of 9 sections), 270 feet. Areal outcrop, 167.25 square miles. This formation, the Lexington limestone of Marius Campbell, 1890, forms the surface rock outcrop over most of the county. No other county in the Inner Blue Grass region of Kentucky exhibits such a large Trenton area. While some slight lithological differences characterize the different beds, it is in general a grayish crystalline limestone. Virtually the same divisions of it can be established here as in the other central counties where it outcrops. Most of them are shown typically in a steep section exposed on the north side of Glenn Creek at the Old Crow distillery. Here in the bed of an old road which leads out of the valley into Franklin County, nearly every layer of rock outcrops from about 10 feet below the top of the Tyrone to 32 feet up into the Eden. This section has already been published.* For "Wilmore" and "Bigby," appearing as names for two of the subdivisions in that published section there should be substituted "Jessamine" and "Benson," respectively, to bring them in harmony with the revised nomenclature. The name of the fossil *Rhynchotrema inaequivalve,* (misspelled in one instance in the section published in the report on Franklin County) should be changed to *Rynchotrema increbescens.*

Curdsville Bed. This lowest bed of the Trenton in Kentucky, named from an old abandoned station on the Cincinnati Southern railroad in Mercer County, is 10 to 20 feet thick. It is separated from the Tyrone by a sharp lithological and paleontological break. The Tyrone, as we have seen, is a fine-grained, dove-colored limestone breaking with a conchoidal fracture and containing few fossils. The Curdsville is a grayish-crystalline limestone with irregular fracture and crowded with fossils. The plane of demarcation between the two beds is quite sharp. In some places it is slightly undulating and in others the grayish-crystalline Curdsville may be seen filling vertical cracks in the Tyrone, which were evidently made after the fine-grained algal mud of the latter had hardened into rock. In other instances angular pieces of Tyrone have been incorporated into the lower four or five inches of the Curdsville. Evidently they had been

*Geology of the Georgetown Quadrangle, Miller, Ky. Geol. Survey, Series IV, Vol. 1, Part 1, p. 321, 1913; also Geology of Franklin County, Miller, Ky. Geol. Survey, Series IV, Vol. II, p. 21, 1914.

broken off by wave or current action from the lower lying Tyrone after it had become hardened sediment and then had become mixed with the sediment then forming at the beginning of Curdsville time. Taken in connection with the ripple marks and sun cracks of the upper portion of the Tyrone, which show shallow water formation and exposure at times to the air, it is evident that in late Tyrone time a relative upward movement of the land began in this region which brought sea bottom above the surface of the sea; that the sediments thus brought above the sea were dried, hardened and eroded; that they again sank below sea level during Curdsville time; and that there was then inaugurated a new epoch of deposition in which changed conditions brought about the laying down of a very different class of limestone sediments. In other words we have here a "disconformity" between the Tyrone and the Curdsville which marks an hiatus between Tyrone and Trenton time unrecorded in this region by any sedimentation. A remarkable feature of this disconformable contact between two formations is that it is so frequently one of complete cementation. The two formations are commonly so closely cemented together that in quarrying operations the layers more readily separate along stratification planes above and below than along this plane of disconformity. A good place to secure specimens of the two formations united into one piece by this sort of cementation is in an old quarry formerly worked to the north of the Glenn Creek pike at Old Crow distillery.

The same fossils characterize the Curdsville in Woodford as in the adjoining counties of Jessamine and Franklin, with which the exposures are continuous. The most characteristic one is the brachiopod *Dinorthis pectinella*. Other brachiopods are *Orthis tricenaria*, *Rhynchotrema subtrigonale*, and *Plectambonites sericeus*. With these are found the lamellibranchs *Vanuxemia dixonensis* and *Cyrtodonta subovata*, the coral *Streptelasma profundum*, and the stem fragments with occasional heads of the crinoids, mostly cystids, belonging to the genera, *Hybocystites*, *Amygdalocystites*, and *Edrioaster*.

Following immediately upon the top of the cliff forming High Bridge series, the Curdsville is found mostly in steep exposures, and has, therefore, entered little into soil formation.

The Hermitage Bed. Identified by E. O. Ulrich as the equivalent of the bed of that name in Tennessee named from the Andrew Jackson homestead. It is from 35 to 45 feet thick in Woodford County. It consists largely of fine-grained argillaceous or siliceous limestones, thin-bedded and intercalated with some shale. The most abundant fossil in it is the brachiopod, *Dalmanella bassleri,* which also passes up through the next succeeding bed. In the upper part of the formation certain layers contain the shells of this fossil packed together in a confused mass as if by current action. Somewhat arbitrarily the

Photograph by A. M. Miller

MASSIVE FAULCONER BED OF THE PERRYVILLE

Louisville and Nashville Railroad Cut, between Duckers and Spring Station.

upper one of these layers has been selected to mark the top of the formation. Other fossils are the brachiopods *Heterorthis clytie,* the lamellibranch *Modiolodon oviformis,* the gastropods *Protowarthia obesa, Protowarthia pervoluta, Liospira micula,* and *Lophosira obliqua,* and the trilobite crustaceans *Isotelus gigas* and *Cryptolithus tesselatus.* The gastropods and lamellibranchs fill certain layers, as abundantly as does the brachiopod *Dalmanella bassleri.* Like the preceding formations the Hermitage does not form extensive outcrops on flat surfaces as it does not reach to the uplands.

The Jessamine Bed. (Wilmore of early reports) was named from Jessamine County. It is about 80 feet thick and

consists of purer limestone than the Hermitage. It occurs mostly in thin layers, though towards the top in places thick ones appear.

The most abundant fossils are the brachiopod *Dalmanella bassleri* and the chocolate-drop shaped bryozoan, *Prasopora simulatrix.* The presence of these two fossils together in the same layer serves to identify it as Jessamine. Towards the top the brachiopod *Hebertella frankfortensis* becomes abundant. In the southern part of the county—that lying south of Clear Creek—this formation reaches into the uplands and there are considerable soil areas formed upon it which are of excellent quality. In the northern portion it outcrops only on the bottom and sides of the stream valleys, and is not so important as a soil former.

The Benson Bed. Named from Benson Creek, Franklin County. This is the bed called "Bigby," in the report on Franklin County. It has been established, however, since that report was issued that the Bigby of Tennessee is the equivalent of both this bed and the next two beds above (Brannon and Woodburn).

The Benson in Woodford County is about 75 feet thick. It differs little lithologically from the Jessamine, and is here discriminated solely on paleontological grounds. The bottom is taken as the horizon where in ascending a section *Prasopora simulatrix* and *Dalmanella bassleri* disappear and the brachiopod *Rhynchotrema increbescens* (*R. inaequivalve* of earlier reports) begins to appear. The brachiopod *Hebertella frankfortensis* ranges throughout the bed. The top is marked by the presence of the problematical fossil *Stromatocerium pustulosum,* which in the northern portion of the county, as in the adjoining counties of Fayette, Scott and Franklin, forms a continuous coralline, hydro-coralline or calcareous algal reef, about five feet thick. The individual *Stromatoceria* in this reef tend to be conical in shape, and may form masses weighing several hundred pounds. They may often be seen built into rock fences, and where they are very regular cones, they have been used as cappings to fence posts to prevent weathering of the latter, and as an ornamental feature.

Associated with this fossil may be found the bryozoan *Cyphotrypa frankfortensis* and the two rare brachiopods, *Strophomena*

vicina and *Dinorthis ulrichi.* The vertical range for these two brachiopods is not over ten feet.

At the same horizon in the middle and southern part of the county, these fossil brachiopods are extremely rare, and the *Stromatoceria* are more scattered and more irregular in shape.

Considerable upland soil of excellent quality is bedded upon this formation.

The Brannon Bed. Named from a station on the Cincinnati Southern railroad in Jessamine County. (In part the Flannagan of M. R. Campbell's report on the Richmond Quadrangle, and of the author's report on Franklin County.) This bed, 15 to 20 feet thick (13 feet thick in the Old Crow distillery section), has an outcrop of 17.52 square miles. It is a fine-grained, siliceous limestone. In the southern part of the county it tends to be thin-bedded with shale between the layers. In the northern portion, in addition to this feature, certain layers are thick and with a concretionary, gnarly or bouldery structure. Fossils are not common in it, but in Franklin County it has yielded in two places the rare sponge *Brachiospongia digitata,* and in northern Fayette County one locality has yielded the equally rare sponge *Pattersonia* (*Strobilospongia*) *aurita.* Other fossils found occasionally in it is a *lamellibranch* belonging to the genus *Byssonychia*, the brachiopods *Rhynchotrema increbescens*, and a *Rafinesquina,* and two trilobites, *Isotelus gigas* and a *Calymene.*

In the northern part of the county where sinks abound they are commonly in this and the next higher formation, the Woodburn, the Brannon forming the throat and the Woodburn forming the bowl-like depression above. It is a common water bearer in the region where it is under cover and many big springs issue at the level of its outcrop. Such is the big town spring at Versailles.

Where the thick-bedded, concretionary phase predominates the Brannon weathers to a cherty soil; where it is thin-bedded and shaly it weathers to a yellow clay soil easily eroded, forming in the southern part of the county, especially in the region around Mortonsville, belts of rather poor gullied land on the hillsides.

The Woodburn Bed. This bed takes its name from Woodburn, the Alexander place near Spring Station. It consists of

about 40 feet of granular, cross-bedded, phosphatic limestones. The phosphate (tricalcium phosphate) exists in the form of inside casts and fragments of casts of the shell of a minute gastropod called *Cyclora minuta.* By the weathering of the limestone the phosphate becomes concentrated in the soil formed from it, especially in the lower portions in contact with the bed rock. An explanation of the chemistry of the process has been

Photograph by A. M. Miller

PHOSPHATIC LIMESTONE QUARRY

This quarry in operation near Wallace Station is the only one of its kind in the Blue Grass Region.

published.* Other characteristic fossils of this bed are the bryozoan, *Constelaria teres,* and the honeycomb coral *Columnaria halli.* The brachiopod *Rhynchotrema increbescens* ranges up into the bed from the underlying Benson and is abundant; also there is an occasional *Stromatocerium* undistinguishable from the reef-forming one at the top of the Benson. The Woodburn, having an areal outcrop in the county of 71.51 square miles, forms the largest continuous upland surface in the northern part. Here, too, it is highest in phosphatic content, giving rise to those deep and inexhaustively rich soils of the region from Versailles northward that have given to this portion of the county the name "Asparagus Bed" of the Blue Grass.

In the region south and southeast from Midway the phosphate has been so concentrated at the bottom of the soil that it

*Geology of the Georgetown Quadrangle, Miller. Ky. Geol. Survey, Series IV, Vol. II, Part I, pp. 317-386, 1914.

is at present worked extensively for that valuable mineral product. The operating company (The Carolina and Virginia Chemical Company) mines it by means of steam shovels, hauls it on trams to the washer and mill near Wallace, and prepares it there for further treatment with sulphuric acid by first washing and grinding it. The product at present goes mostly to form phosphate drinks and phosphate baking powders. This mill has a capacity for preparing between 60 and 100 tons per day of ground rock phosphate. The company pays a royalty to the landowner of fifty cents per ton for the crude phosphate, and the land yields from 1,500 to 3,000 tons of phosphate per acre. The removal of the rock leaves the land in a ruined condition agriculturally for apparently a long time to come, but as the owner receives in royalties from \$700 to \$1,500 per acre for his land, he may feel himself well compensated for the destruction, if he lays feelings of sentiment aside. The author claims the credit for having first discovered and called attention to the commercial possibilities of these phosphate deposits in northern Woodford County. His report prepared for the Norwood Survey on work done in 1904 called especial attention to these deposits, but as it was never published his discovery remained unknown to the outside world and in the summer of 1915 they were independently "rediscovered" on the land of H. L. Martin, which discovery led to the subsequent development. (See, for a history of the discovery of phosphate in Kentucky, W. C. Phalen's report on Phosphate Rocks in Central Kentucky, Kentucky and U. S. Geological Surveys, Frankfort, Ky., 1915.)

The Perryville Bed. Named from the village of Perryville in Boyle County. This bed has an outcrop area in Woodford County of 4.93 square miles. In Boyle and Mercer counties it consists in ascending order of three members—Faulconer, Salvisa and Cornishville. It being followed northward on the west side of the Kentucky river the top member, the Cornishville, drops out, so that in Franklin County only the two lower members are present. In the lower Benson Creek region these may reach a combined thickness of 25 feet, about 6 to 8 feet of which belongs to the Faulconer. This thickness to the Faulconer is preserved in its passage over into northern Woodford County, but the Salvisa has thinned until there it is not more than 5 feet

thick. In the region to the south of the Versailles-Clifton pike and west of the McCowan's Ferry pike the Perryville is entirely absent at the horizon where due; the Cynthiana, the next overlying formation, resting there directly upon the Woodburn.

The Faulconer member (name derived from the station in Boyle County on the Cincinnati Southern railroad) is a massive bed, often consisting of a single layer 6 to 8 feet thick, which is a mass of fossil shells—mostly of gastropods—though with them are mixed a few belonging to lamellibranchs. It is as much a true "coquina" as the well known shell rock of Florida from which the walls of St. Augustine were built. Characteristic fossils of the Faulconer are the gastropods, *Bellerophon troosti, Oxydiscus subacutus,* and *Lophospira* (species *medialis* or *sumnerensis*). A typical exposure of this bed may be seen in the railroad cut of the Louisville and Nashville railroad where the old Frankfort pike crosses it by an overhead bridge west of Spring Station. The rock has been quarried to some extent for the making of large gateposts such as mark the entrances to certain country estates in the region. It weathers to a porous chert in which the different fossil shells stand out with great distinctness.

The Salvisa (name derived from a village in Mercer County) is, where typically developed, a fine-grained limestone breaking with a conchoidal fracture. In Boyle and Mercer counties it so closely resembles in lithological character the Tyrone limestone, that William Linney called it the "Upper Birdseye."

In Woodford County it seldom has the typical dove color which with the calcite facets make it so closely resemble the Tyrone in the counties to the south. Instead, though weathering white, like the Tyrone, it is dark gray on the inside. It is hard and brittle under the hammer. Typical fossils are the ostracods *Leperditia caecigena,* and *Isochilina jonesi.* The former, resembling flax seed superficially, generally shows up in great numbers making up the whole substance of the rock. The latter is not so numerous, and may be wanting entirely in certain exposures, but it is larger, often being one-half to three-quarters of an inch in length. The shells, which are black and shining, are very conspicuous objects on the fresh surfaces of the rock as they are revealed under the blows of the hammer. The best lo-

cality for obtaining fine specimens of this striking fossil is the first conspicuous rock exposure on the left in passing north of the pike from Knight's corner to the mouth of Glen Creek. Other fossils are the cephalopods, *Orthoceras milleri*, and a *Cyrtoceras*, and the brachiopod *Orthorhynchula linneyi*. In the exposure in the cut of the Louisville and Nashville railroad referred to in the description of the Faulconer member, the Salvisa is scarcely recognizable as such, consisting there of a few thin shaly layers. Some of these, however, are crowded with the fossil *Leperditia caecigena*.

Photograph by A. M. Miller

PHOSPHATE ROCK PLANT

This grinding mill and washer is owned and operated by the Virginia and Carolina Chemical Co. and is located near Wallace, Ky.

The farthest eastern exposure of the Perryville on the western side of the Cincinnati arch, and the ones which come closest to its axis, are the small patches indicated on the map as lying south of the old Frankfort pike and between the Mt. Pisgah and Mt. Vernon pikes.

Cincinnatian Series

The Cynthiana Stage. This formation, named from the county seat of Harrison County, has in Woodford County a thickness of about 40 feet and an aggregate areal outcrop of 9.15 square miles. In this county it presents the usual lithological characteristics and carries the same fauna—the Greendale fauna

—of its other exposures in the central Blue Grass region. The limestone, bluish on fresh structures, tends to weather to a rusty red and breaks up into "rubbly" pieces. It carries more shale than the formation immediately below it, so that the soils from it tend to wash more.

The most characteristic fossil, as elsewhere in Kentucky, is the gastropod, *Cyclonema varicosum.* Other fossils found in almost every exposure are the brachiopods *Rafinesquina winchesterensis, Platystrophia colbiensis, Hebertella sinuata;* the bryozoan *Eridotrypa briarius;* and the lamellibranchs *Orthodesma* (sp.?), *Byssonychia* (sp.?) and *Allonychia flannaganensis.* For a more complete list see the author's report on Franklin County.

The exposures of the Cynthiana occur in disconnected patches, mostly in the northwestern portion of the county, where they are surrounded by a narrow outcrop of Perryville. There is a fair sized area south and southeast of Versailles and extending into the southern limits of the town. Another patch is west of Versailles, mostly south of the Clifton pike. Smaller patches are found near Milner on the Louisville Southern railroad, and there are small patches on the watershed between Grier and Craig Creeks. The patches west of Versailles and south of the Clifton pike rest directly on the Woodburn formation, the Perryville being entirely absent, as has been previously stated.

The Cynthiana gives rise to good soils, but they are inferior to those formed from members of the Trenton series, and they contrast especially in this respect with those formed from the Woodburn.

The Eden Bed. This formation so extensively developed in the belt immediately encircling the Inner Blue Grass region, occurs in this county only in a few scattered outliers in the northwestern portion, where it is found capping the highest portions of this section. It here attains a maximum thickness of fifty feet representing the lowest portion of the formation. It has a combined areal outcrop of only .7 square mile. It is characterized here by the same lithological characteristics and carries the same fossils as this portion of the formation elsewhere in north central Kentucky. Thin-bedded, dense limestone alternating with considerable shale is the characteristic feature of its out-

crop. The index fossil for this formation, a *Plectambonites* which has been identified as *sericeus* and again as *rugosus*, but which is evidently different from either, is, except within ten feet of the base, everywhere present, covering slabs of limestones which on weathering slip out from the shale and are found scattered over the steep and somewhat bare hillsides. These bare and gullied hillsides worn down to the yellow subsoil are a feature of the outcrop of this formation. The soil formed from the Eden is relatively poor, contrasting strongly with the high fertility of the other soil areas adjacent to it.

One of the Eden areas is crossed by the Versailles-Frankfort pike between McKee's Crossroads and the Woodford-Franklin county line. The others are in that region west of lower Glenn Creek known locally as "Germany" on account of the fact that a number of German farmers early settled in that region.

Tertiary System

Irvine Formation. Belonging to the unconsolidated deposits which cover all the older rocks in the vicinity of the Kentucky river, are the loams, sands, gravels and small boulders which, from their water-worn character and the nature of the materials, were evidently brought down and deposited by the Kentucky river during a preceding cycle of erosion. They are especially abundant in the southern part of the county south of Clear Creek, where they are found on top of the highest hills. The gravel consists of quartz pebbles from the basal coal measure conglomerate which were evidently brought down from the outcrops of that formation along the western margin of the eastern coal field where trenched by the Kentucky river and its tributaries. Mingled with these are a large number of geodes from the upper Waverly. These geodes are most abundant in the Waverly outcrop of the Dicks river drainage, and it looks as if this region was their source. The geological age of these deposits is in dispute. M. R. Campbell, who first described them in 1898 in his Geology of the Richmond Quadrangle, where he named them the "Irvine Formation," attempted a no more definite classification of them than "Neocene." Where abundant these deposits usually detract from the arability of the land.

In a few instances fragments of the fossil bones and teeth of extinct mammals (a tapir, a horse and a deer different from the modern species) have been found in these deposits. These seem to indicate the late Pliocene or early Pleistocene as their most probable age. They certainly antedate in age the gorge of the Kentucky river, having been spread over a broad alluvial plain during the wide meanderings of the river before it had cut its present gorge.

Mineral Veins and Faults

A number of mineral veins are found in the county. They have a general north and south course, are from a few inches to four or five feet wide, and have as their vein material, barite, calcite and fluorite, or a mingling of these minerals. They are found traversing the rock of the Trenton or Highbridge series. When in the former their filling is generally barite, when in the latter it is found to be chiefly calcite or fluorite.

In the early days shafts were frequently sunk on them in the hope of finding lead, which occurs sparingly in them in the form of its leading ore—galenite. Sphalerite, zinc sulphide ore, also frequently accompanies the galenite. All such attempts were unsuccessful. More recently many of them have been prospected for barite, calcite and fluorite (fluorspar), but with only moderate success. The positions of the leading veins are indicated on the accompanying geological map.

The most important of these veins is the one known as the Faircloth vein, which has been worked for fluorspar. It is exposed in the face of the river cliff back of the old Faircloth residence, more recently occupied by the late Colonel Jack Chinn. An adit toward the base of the cliff has been run back on this vein for a distance of 150 feet, and toward the top of the cliff another extensive adit and trenches have been more recently run and dug upon it. In addition to ordinary commercial fluorspar some very good "optical fluorspar" has been obtained from this vein.

There is only one fault in the county—a very small one four and one-half miles notheastward from Versailles on the Mt. Vernon or Big Sink pike. It crosses this pike a short distance north of the crossroads, which is one and one-half miles south of the

intersection of the pike with the old Frankfort pike. The length of the fault is about three-fourths of a mile, the strike north about 40 degrees west, and the throw, which displaces Cynthiana on Woodburn, is 20 to 40 feet.

Native Trees and Shrubs

Very little native forest growth has been preserved in the county. On some of the larger country estates there are still left some fine woodlands, but most of these have been cut down to make more acreage for tobacco. Along the steep hillsides of the Kentucky river and the lower courses of its tributaries there is a good deal of thick forest growth from which all the merchantable timber has been cut. The characteristic trees of the county are the same as those in the adjoining county of Franklin and have already been listed.*

There may be enumerated from this list the two special kinds of oaks—the burr and the chinquapin—which, with the ash, walnut, hackberry and wild cherry, are so characteristic of the Inner Blue Grass uplands, and the beech, which is here seldom found elsewhere than on the river and lower tributary stream bottoms.

References on Woodford County

FOERSTE, AUGUST F.

Phosphate deposits in the upper Trenton limestones of Central Kentucky: Hoeing Kentucky Geological Survey, series 4, vol. 2, part 1, pp. 387-439. figs. 2, map, 1913.

FOHS, F. JULIUS.

Barytes deposits in Kentucky: Hoeing Kentucky Geological Survey, series 4, vol. 2, part 1, pp. 441-576, 1913.

Fluorspar deposits of Kentucky with notes on the production, mining and technology of the mineral in the United States; also some data concerning barite deposits: Norwood Kentucky Geological Survey, Bulletin No. 9, pp. 296, pls. 26, 1907.

GARDNER, JAMES H.

Rock phosphate in Kentucky: Mines and Minerals, vol. 33, pp. 207-209, figs. 3, 1912.

JILLSON, W. R.

Geological Map of Kentucky. Scale 1 in.=10 miles. Colored. Ky. Geol. Survey, 1923.

*Geology of Franklin County, Miller. Ky. Geol. Survey, Series IV, Vol. II.

MATSON, G. C.

Water resources of the Bluegrass region of Kentucky, with chapter on quality of the waters by Chase Palmer: U. S. Geological Survey, Water Supply Paper, No. 223, p. 223, pls. 3, figs. 1909.

MILLER, ARTHUR M.

Geology of the Georgetown Quadrangle: Hoeing Kentucky Geological Survey, series 4, vol. 2, part 1, pp. 317-386, 1913.

Lead and zinc bearing rocks of Central Kentucky, with notes on the mineral veins: Norwood Kentucky Geological Survey, Bulletin No. 2, pp. 35, pls. 8, fig. 1, 1905.

Ordovician Cynthianan formation: Am. Journ. Sci., vol. 40, art. 47, pp 651, and reprint, Dec., 1915.

Geological Map of Woodford County, Ky. Scale, 1 in.=1 mi.: Kentucky Geological Survey, 1925.

PETER, DR. ROBERT

Woodford County limestones and soils: Owen Kentucky Geological Survey, vol. 2, pp. 279-286, 1857.

Woodford County, rocks and soils of: Owen Kentucky Geological Survey, vol. 3, pp. 64-66, 1857.

Woodford County, mineral waters: Owen Kentucky Geological Survey, vol. 4, O. 270, 1861.

Woodford County, rocks, soils and mineral water: Procter Kentucky Geological Survey, Chemical Analyses, vol. A, part 2, pp. 123, 124 and 248, 1885.

PHALEN, W. C.

Phosphate rocks of Central Kentucky: Hoeing Kentucky Geological Survey, pp. 80, pls. 19, maps 2, Nov.. 1915.

VI.

THE INTRASTATE INDUSTRIAL UTILIZATION OF THE MINERAL RESOURCES OF KENTUCKY

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Kentucky was early sought out and settled by emigrants in quest of rich agricultural lands and undispoiled hunting preserves. Almost coincident with this settlement the mineral resources of the state came to be valued: first for local consumption, and later for export. As early as 1838 William Williams Mather, the first state employed Geologist of Kentucky,[1] pointed out a long list of minerals occurring in this state. Coal was foreseen by this geologist to be the great resource of Kentucky, but included in the list were many others, such as petroleum, fluorspar, building stones and clays, which at that date were but slightly in demand.

During the half century which followed Dr. Mather's geological reconnaissance in Kentucky, the truth of his prophetic statement became more and more apparent as the early geological surveys of the state began unravelling its geology and mineral resources. Though slow to attract national attention because of their location in a supposedly agricultural state, Kentucky's resources have rapidly come to the front since 1890. Within recent years the fluorspar of western Kentucky has become a staple in the steel and aluminum industries of America. The same is true of extended fire clay deposits in northeastern Kentucky. The petroleum fields of Kentucky have grown to an extent wherein from a standpoint of actual production they are first in the Appalachian region. Standing fourth in coal production in the nation during the last year Kentucky may point with pride to the fact that her northeastern and southeastern coal fields during the past decade were the greatest in expansion of any major coal field in the United States. An examination of the industrial use of the extended list of raw mineral ma-

[1] W. R. Jillson, "Geological Research in Kentucky," Kentucky Geological Survey, Series VI, Vol. 15, 1923.

terials produced in Kentucky, gives a true prospectus of the importance of this state in the economic fabric of the Union.

Indeed, it has been said* that "The state of Kentucky is one of the richest mineral resource storehouses of the Appalachian region. Within its area of 40,598 square miles there are found in commercial and smaller quantities in the crude or natural state about thirty separate minerals from which a great number of mineral products may be manufactured or refined. The list of the minerals and direct mineral products of Kentucky follows: (1) Abrasives; (2) aragonite; (3) artificial gas; (4) asphalt rock; (5) barytes; (6) calcite; (7) carbon black; (8) cement; (9) clay products (pottery, tile, brick, etc.); (10) Coal (bituminous and cannel); (11) coke (beehive and by-product); (12) copper; (13) fluorspar; (14) gravel; (15) gypsum; (16) iron; (17) lead; (18) lime; (19) marble; (20) mica; (21) mineral fertilizer; (22) mineral waters; (23) natural gas; (24) ochre; (25) oil shale; (26) petroleum; (27) phosphate rock; (28) potash; (29) salt; (30) sand; (31) silver; (32) stone, and (33) Zinc." To be sure, some of these minerals such as copper, gypsum, mica and potash, occur so rarely or in such small amount that they are of no importance commercially and others, such as abrasives, argonite, calcite, iron, marble, ochre, oil shale and salt, though occurring in large amounts, are either not operated at all at present or only in a small way.

Nevertheless, in the year 1921, the following minerals and mineral products were produced commercially in Kentucky: Artificial gas, asphalt rock, barytes, carbon black, cement, clay (and shale), coal, coke, fluorspar, lead, lime, mineral waters, natural gas, natural gas gasoline, petroleum, phosphate rock, sand and gravel, stone, tar and zinc, the three minerals having the largest known production and value in the state for the period, 1918-1920, being coal, petroleum and fluorspar respectively.

Thus it is seen that Kentucky, though generally considered an agricultural state, nevertheless is also a mining state and one that is well up in the list. In fact, according to the United States Bureau of the Census, Kentucky, which ranked thirty-sixth in size and fifteenth in population in 1919, ranked tenth in

*Jillson, W. R., Recent Mineral Production in Kentucky, The Sixth Geological Survey, Kentucky Geological Survey, page 261, 1921.

the value of raw mineral products and fifth in the total number of persons engaged in the mining industries and in the average number of wage earners employed. In this year there were the following producing enterprises in the state: Asphalt, one; barytes, five; clay, eighteen; bituminous coal, six hundred and thirty-five; fluorspar, twenty-nine; limestone, forty-seven; mineral pigments, one; petroleum and natural gas, one hundred and ninety-six; phosphate rock, one; sandstone, five; making a total of nine hundred and thirty-eight. At the same time the gross value of the products of all mines, quarries and wells amounted to $98,445,806, an increase in the ten year period from 1909 of over 700%.

The great mineral wealth of Kentucky has been briefly outlined. In the following pages an attempt has been made to outline the industrial utilization of the natural resources of the State in some detail.

In 1920 there were eight cities within Kentucky with a population of more than ten thousand persons. These were Ashland, Covington, Henderson, Lexington, Louisville, Newport, Owensboro and Paducah, with a combined population of 431,920, or 17.9% of the total number of the people in the state. In 1919 these same cities reported 34.5% of the total number of industrial plants within the state, which plants produced 72.7% of the total value of the state's manufactured products. Of these cities, Jefferson County, in which is situated the city of Louisville, led with 53.1% of the total value of products and 44.6% of the average number of wage earners.

Among the industrial plants in operation during that year were numbered steel works and rolling mills, 5; foundries and machine shops, 87; clay working establishments, 47; blast furnaces, 4; paint manufacturers, 13; marble and stone works, 63; and paving material plants, 38. Manifestly not all nor nearly all the plants listed by the Bureau of the Census utilize Kentucky's natural mineral resources either wholly or in part, as raw materials, and there have also been changes in the number of plants in operation in the past three or four years, the preceding data being given merely as an indication of the distribution of the manufacturing industries within the state.

However, the only industrial plants of interest in this discussion are those which utilize wholly or in part the natural mineral resources of Kentucky as their raw materials and the following pages will be devoted to a brief discussion of such plants.

The Industrial Utilization of Coal

It would manifestly be impossible to list all of the users of Kentucky coal within the state. Suffice it to say that practically all the bituminous and cannel coal used within Kentucky for industrial, steam, railroad and all other purposes is a product of the mines of the state and probably 10% to 20% of the coal produced is so used, the rest being shipped outside the state boundaries.

In this connection it might be interesting to note that the United States Geological Survey statistics for 1921 give the total amount of coal mined in that year as 31,588,270 tons. Of this total, 802,744 tons, or about 2.5% was sold to the local trade and used by employes, 527,257 tons, or about 1.7% was used at the mines for steam and heat and 161,507 tons, or about 0.5% was made into coke at the mines. The remainder, or 30,096,762 tons, about 95.3% of the total, was loaded at the mines for shipment.

Coke

One of the great uses for bituminous coal is in the manufacture of coke for metallurgical purposes. To be sure, in order to make coke, the coal must be what is known as a coking coal, but, fortunately, Kentucky is endowed with a plentiful supply of some of the best coking coal in the United States, this coal being found in the eastern coal fields.

At the present time the coke industry within the state is very small compared to the amount of coking coal available. There are various reasons for this, among the most important being that coke is always made as close as possible to the point where it is going to be used. This is because coke is very friable and breaks easily while being transported and handled, which fact tends to destroy its usefulness for metallurgical purposes, while it makes little difference if the coal from which the coke is to be made does break up because, during the process of manufacture into coke, it is again melted together. Again, a great

deal of the metallurgical coke is manufactured in what is known as by-product plants. These plants produce not only coke but various by-products as well, chief among which is gas. In order to dispose of this gas the coke plant must be situated either near some industry that can utilize it or else near some large city where it can be used for domestic as well as industrial purposes. For these reasons large quantities of Kentucky's coking coal are shipped to Gary, Indiana, and the Chicago steel district for subsequent manufacture into coke. Kentucky at the present time being rather lacking in metallurgical plants, which could assimilate both the coke and the by-product gas made, and also being plentifully supplied with natural gas for domestic and other industrial purposes, the development of the by-product coking industry has suffered accordingly.

However, when the time comes, as come it will, when the iron ore deposits of the state are developed and an iron and steel industry comparable with the raw material resources available comes into being, then, as a corollary, a by-product coking industry will arise which should put Kentucky into the first rank of the states in this respect.

The United States Geological Survey shows that of the 24,492,504 tons of coal mined in the eastern district of Kentucky in 1920, only 446,971 tons were made into coke at the mines, this coke undoubtedly having been made by the beehive method, whereby all the by-products go to waste. Of this total tonnage 200 tons were used in Bell County, 250,376 tons in Harlan County, 438 tons in Perry County and 195,957 tons in Pike County. In 1921 the same authority gives only 161,507 tons of coal utilized at the mines in making coke out of a total tonnage from eastern Kentucky of 22,972,414 tons, a falling off of 285,464 tons or about 64% from the preceding year. Of the total amount of coal utilized in this year for this purpose 45,992 tons were so used in Harlan County, and 115,515 tons in Pike County. In addition, Mr. Lawson Blenkinsopp, State Inspector of Mines, states that in the first six months of 1923 the Wisconsin Steel Co., at Benham, in Harlan County, manufactured 55,850 tons of beehive coke. The reason that figures are given on the eastern Kentucky coal field alone is because only coal from this district is being utilized in the manufacture of coke.

As far as by-product coke is concerned, it may be said that there is only one by-product plant in operation in Kentucky at the present time and this is the plant of the Ashland By-product Coke Company, at Ashland. This company uses between 500,000 and 600,000 tons of Kentucky coal annually in the production of coke and by-products, a large part of the coke and gas made being utilized in the iron and steel industry located in and around Ashland.

It has been mentioned that gas is a by-product from the retort method of coking, but gas for domestic and industrial use can be made from coal by other methods as well, the method used depending largely on whether the coke or the gas is to be the main product. As long as Kentucky is as well supplied with natural gas as she is at present there will be no great growth of the artificial gas industry, for domestic use at least, but when the time comes, as is bound to happen, when the natural gas resources of the state are exhausted, then there will be a very rapid growth in the artificial gas industry and a large amount of coal will be utilized for this purpose. Indeed, there is a plant at this time making artificial gas at Owensboro. Jillson gives the figures for the production of artificial gas in the state in 1918 as 4,279,853,000 cubic feet of a total value of $202,914.

Thus it is seen that, of necessity, the great bulk of the coal produced in Kentucky is consumed outside of the state, the manufacture of coke and gas forming virtually the only opportunity for future development along this line, and this in turn, depending largely on the growth of an iron and steel industry and the failing of the natural gas supply.

The Industrial Utilization of Petroleum

A brief word in regard to the production of petroleum may be of interest and value at this point. In 1918 Kentucky ranked twelfth in the production of crude oil, but in 1921 it advanced to ninth through the doubling of her production, which was approximately 9,000,000 barrels in 1919, 1920, 1921 and 1922. This was due, chiefly, to developments in Lee, Estill, Allen and Warren counties, the decreased production in the two former counties in 1921 being counterbalanced by increases in Warren County. The marked fluctuation in prices that may take place

in the oil industry is very clearly shown by the fact that in 1920 Kentucky produced 8,738,000 barrels of oil valued at $34,279,000 at the wells, while in 1921, with a production increased to 9,013,000 barrels, the value at the wells had decreased over half to $16,736,000.

According to the United States Geological Survey, on December 31, 1921, there were in Kentucky approximately 9,200 producing oil wells, giving an approximate production per well per day of 2.7 barrels. The total number of wells drilled in the state in 1919 was 3,702, 3,165 of these being oil wells, 130 gas wells, and 407 dry holes; in 1920 the figures were 2,873 total, 2,542 oil, 66 gas, and 265 dry; and in 1921, 2,468 total, 1,935 oil, 64 gas, and 469 dry, the latter year showing the dry holes to have been 19% of the entire number drilled, thus indicating that development had about reached its climax. Another straw showing this is the fact that in 1919 the average initial daily production per well in barrels was 33.8, in 1920 31.3, and in 1921 this figure had dropped to 20.9 barrels.

Crude petroleum is rarely sold as such for ultimate consumption, the raw material being refined in order to produce gasoline, kerosene, fuel oil, etc. In order to treat this oil refineries must be established, and there are many such in Kentucky. In the following paragraphs will be given a list of the refineries in the state, both large and small, but no attempt will be made to give the amount of crude oil put through these refineries per year, in all cases, nor even to indicate whether the plants are working at this time or not. This is because of the peculiar conditions existing at the time of writing this paper. Due to various reasons, both the crude petroleum market and the market for refinery products at this time, September, 1923, is down, and many refineries that ordinarily operate are either not doing so at all or at reduced capacity. Again, certain refineries operate at one time on Kentucky crude and at other times on crude from other states, depending on which can be obtained the more cheaply. For these reasons it would be manifestly unfair to give the consumption of crude oil by Kentucky refineries at this time. However, it may be said that a large proportion of the crude petroleum produced in Kentucky is refined within the state.

At Bowling Green, in Warren County, are located three refineries: The Park City Refinery, the E. K. Riggs Refinery, and Ulf Brothers Refinery. Mr. E. K. Riggs, of the Riggs Refinery, states that this plant uses yearly 7,000 barrels of fuel oil valued at $8,500 for fuel for operating the refinery and that approximately 75,000 barrels of Kentucky crude oil, valued at $150,000, is refined annually through this establishment.

At Burkesville, in Cumberland County, is located the Cumberland County Refinery, which operates on crude produced, chiefly, in the comparatively near vicinity.

At Campton Junction, in Powell County, the Neha Refining Co., with offices at Lexington, operates a refinery. This company uses approximately 15,000 barrels of fuel oil per year for fuel at the refinery and refines through the plant from 200,000 to 225,000 barrels of Kentucky crude oil annually.

At Creelsboro, in Russell County, a refinery is operated by the Carnahan Oil and Refining Company.

At Franklin, in Simpson County, the Western Kentucky Refining Company owns and operates a refinery.

At Latonia, in Kenton County, the Petroleum Refining Company, with postoffice address at Latonia Station, Covington, operates a refinery whose throughput is approximately 500,000 barrels of Kentucky crude oil per year.

At Leach, in Boyd County, a refinery is operated by the Great Eastern Refining Company.

At Lexington, in Fayette County, two refineries are located, one large and one small. The large one is that of the Great Southern Refining Company, which operates on crude oil from the eastern Kentucky fields. The smaller one is the plant of the Old Kentucky Refining Company, which operates on oil from the same locality.

At Louisville, in Jefferson County, three refineries are located: That of the Standard Oil Company of Kentucky; that of the Louisa Company of Kentucky, and that of the Stoll Oil Refining Company.

The Standard Oil Company of Kentucky has a large plant in which they are using about ten car loads of Kentucky coal per day for fuel purposes. They also refine considerable quantities of Kentucky crude oil, but the amount cannot be stated as

it varies with the price at which the oil can be purchased compared with the delivered price of other crude oils.

The Louisa Company of Kentucky, which is the successor of the Aetna Refining Company, uses approximately 200,000 barrels of Kentucky crude per year in their refinery when it is operating.

The refinery of the Stoll Refining Company is a large one and is being made larger in some of its departments, a wax house and cold settling plant to make paraffin wax out of Kentucky oils being under construction at this time with the expectation that it will be in operation by January 1st, 1924. In regard to throughput through the refinery, Mr. Berry V. Stoll states: "We use approximately 1,000 barrels a day of crude petroleum. although we are enlarging our plant somewhat, and in six months' time expect to be using about 1,500 or 2,000 barrels a day.

"All of this oil comes from Lee County, Kentucky, although it is quite likely that we will begin to barge the oil down from Catlettsburg, Ky., or from the Cumberland loading rack on the Kentucky river, located up in that section." The products of this refinery are known under the trade names of "Silver Tip" gasoline; "Viscoyle" motor oil and "Green Drip" cylinder oil. The company also maintains distributing stations throughout Kentucky, southern Indiana and southern Ohio for the sale of their products which are well and favorably known in these districts.

At the present time this plant is completely refining about 360,000 barrels of Kentucky crude a year and selling about 75% of it in the state, though the expectation is, as stated above, to considerably increase this amount in the near future.

At Paintsville, in Johnson County, is located the refinery of the Big Sandy Oil and Refining Company. However, due to the poor conditions in the oil business, this plant is shut down at the present time.

At Pryse, in Estill County, the Great Southern Refining Company of Lexington, operates a small plant.

At Scottsville, in Allen County, is located the plant of the Massie Refining Company.

The data given above would seem to indicate that the refining field in Kentucky is pretty well covered.

The Industrial Utilization of Natural Gas

Because of the mode of occurrence of natural gas and the methods of its development, the industry is hazardous even for large operators. The investment for wells and pipe lines in the producing fields must not be so great as to prevent the investors from realizing, during the period of use, a sum sufficient to repay the original investment and provide for interest and profit. Furthermore, once the gas has been gathered into pipe lines, it must be moved promptly. In general, not more than twenty-four hours' supply of gas will be available in the pipes and holders of a company, and in the winter season when the system is worked to its full capacity, only a small fraction of a day's supply may be on hand at any moment. It is therefore evident that the consumption must be closely coordinated with the demand. In no other business, save that of supplying electrical energy, must the producer control his output so exactly in accordance with the needs of the consumer who may be miles away.

Natural gas may be utilized in several ways, among which are as a domestic and industrial fuel, as a raw material for the production of carbon black, and as the material from which natural gas gasoline is produced. If used in either of the former two ways the gas is burned up and destroyed. If used for the latter purpose mentioned the gas, after the removal of the gasoline and its consequent reduction in volume, may be further utilized either as a fuel or for carbon black manufacture.

Natural gas is utilized in Kentucky in all of the above mentioned ways and its use is very widespread. Indeed, not only is the gas produced in the state utilized, but a large amount is imported from West Virginia and Indiana, chiefly the former. According to the United States Geological Survey, Kentucky, in 1921, produced 4,820,000,000 cubic feet of natural gas, this being 0.7% of the total gas produced in the United States, of a value at the point of consumption of $1,597,000, but in the same year she consumed 13,667,000,000 cubic feet, which is 2.1% of the total amount of gas used in that year, of a value of $4,526,000. The figures show that not only did Kentucky use all the gas produced in the state, but about twice as much again. 8,000,00 cubic feet of the gas so imported came from Indiana and

the bulk of it, or 8,839,000,000 cubic feet came from West Virginia.

In 1918 and 1919 Kentucky ranked thirteenth in the production of natural gas, in 1920 twelfth, and in 1921 eleventh, while in all these years she ranked eleventh among the consumers.

According to the above mentioned authority, the greatest problem of the natural gas industry is that of avoiding or reducing waste. Probably 30% of the gas produced at present and started on its way toward users never finds any useful application and of the gas that reaches consumers as much as 50% is used unnecessarily because of inefficient methods of consumption. In Kentucky for the year 1921, the waste of natural gas is given as 1,815,000,000 cubic feet, or 27% of the total consumption for that year.

Domestic Consumption of Natural Gas

Between 30% and 40% of the natural gas consumed in the United States is used by domestic consumers, the remainder being used in industrial operations of various sorts. In Kentucky, in the year 1921, 8,794,000,000 cubic feet of gas of a value of $3,617,000 was used for domestic purposes, this being 41.3% of the total amount of gas consumed within the state for that year. Because of the nearly universal use of natural gas domestically, there being in 1921 100,800 consumers, it would be highly impractical to attempt to give a list of even the large users. However, it may be said that the Central Kentucky Natural Gas Company, with its corporate office at Lexington and its executive office at Oil City, Pa., distributed and handled through their lines in 1922, 612,156,000 cubic feet of Kentucky gas, valued at (selling price) $241,647. Also that the Louisville Gas and Electric Company of Louisville, used, during 1922, 1,500,000,000 cubic feet of Kentucky gas, all but 120,000 cubic feet of which coming from the eastern Kentucky fields. During 1923 this company will use 3,000,000,000 cubic feet and during 1924, 3,500,000,000 cubic feet.

Industrial Consumption of Natural Gas

According to the United States Geological Survey Kentucky, in 1921, consumed 3,150,000,000 cubic feet of gas of a value of

$475,000 in manufacturing; 719,000,000 cubic feet of a value of $208,000 in drilling and pumping; 357,000,000 cubic feet of a value of $36,000 in the manufacture of natural gas gasoline, this figure representing only the actual decrease in volume of the gas treated; and 689,000,000 cubic feet of a value of $190,000 in other operations, including the manufacture of carbon black, this making a total of 4,918,000,000 cubic feet of gas used industrially in the state in 1921 of an aggregate value of $909,000.

Natural Gas By-products

The two principal by-products of natural gas are natural gas gasoline and carbon black. The recovery of gasoline from natural gas is an operation of conservation for it makes available for most efficient application constituents which are not at all essential to the use of the rest of the gas as a domestic or industrial fuel. When carbon black is made from natural gas, however, the gas is burned, and only that portion of it which is recovered as carbon can be further employed. Because the carbon black recovered represents only a small percentage of the total in the gas the argument has been advanced that this use of gas is contrary to the best interests of the public and should be prohibited, and, in fact, it has been so prohibited in some parts of the country.

Natural Gas Gasoline

This term, as used, includes the gasoline recovered by all methods from both "wet" and "dry" natural gas and is synonymous with the term "caseing head gasoline," as used in the industry.

Due to the fact that the manufacture of natural gas gasoline does not destroy the value of the gas for further use no attempt has been made to tabulate the amount of gas passing through the different plants in the state. However, in the following paragraphs, a list of such plants will be given.

At Leach, in Boyd County, the Columbia Gas and Electric Company of Charleston, West Virginia, operates a natural gas gasoline plant but, as none of the gas used originates in Kentucky, it is not of interest in the present discussion.

At Chambers, in Menifee County, the Menifee Gasoline Corporation of Charleston, West Virginia, operates a plant which

is located on the main pipe line of the Central Kentucky Natural Gas Company. The amount of fuel gas used at this plant is approximately 1,000,000 cubic feet per month.

At Cannel City, in Morgan County, is located the plant of the Collier Oil and Gas Company.

At Fixer, in Lee County, which is about seven miles from the Louisville and Nashville railroad at Fincastle, the Cumberland Gasoline Corporation of Cleveland, Ohio, operates a natural gas gasoline plant. The name of this company was formerly the Mississippi River Oil Company, the name having been changed in 1920. This company is using approximately $3,500 worth of natural gas a month.

At Oil Valley, below Monticello, in Wayne County, the Wood Oil Company, with offices at Monticello is making natural gas gasoline by the compression method.

Above Torrent, in Wolfe County, the Superior Oil Company, with offices at Lexington, owns a plant.

At Winchester, in Clark County, the Louisville Gas and Electric Company operates a plant for the production of natural gas gasoline. The approximate volume of Kentucky gas which this company expects to pass through this plant in the year 1923 is 3,500,000,000 cubic feet.

Carbon Black

Carbon black is a fluffy, velvety, black pigment produced by the incomplete combustion of natural gas, burned with a smoky flame against a metal surface. It is quite different from, and much superior to, lamp black, which is made by burning oil or other carbonaceous material with insufficient air for complete combustion and collecting the smoke in settling chambers.

Carbon black is used principally in printers' ink, in the manufacture of rubber tires and in paints, though about 10% of that produced annually is distributed for miscellaneous purposes, such as the manufacture of stove and shoe polish, phonograph records, black leather, bookbinder's board, buttons, carbon and other black or gray papers, typewriter ribbons, carriage cloth, celluloid, electric insulators, cement colors, crayons, drawing and marking inks, artificial stone, black tile and tarpaulin.

According to the United States Geological Survey Kentucky, in 1921, with two plants, produced 2,700,000 pounds of carbon

black of a value of $216,000, using for this purpose approximately 1,519,000,000 cubic feet of natural gas. At the present time there are more carbon black plants in the state than there were in 1921, a brief summary of these plants being given below.

At Campbellsville the Green River Oil and Gas Company operates a carbon black plant.

There are two plants located in Floyd County. One of these is the plant of the Liberty Carbon Black Company at Lem and the other that of the Eastern Carbon Black Company, both enterprises being controlled by West Virginia Capital. The size of the former plant is twenty double machine condenser buildings and the value of the gas utilized per year by this company is approximately $65,000.

Lynn S. Horner and associates of Clarksburg, West Virginia, are operating a small plant near Greensburg, Kentucky.

The Cumberland Gas and Refining Company, formerly the Iroquois Oil and Gas Company, of Williamsburg, Ky., reports that there are approximately 3,000,000 cubic feet of natural gas being used there each week in the manufacture of carbon black, but that it is hoped through further development to increase this consumption to 12,000,000 cubic feet weekly. This black is made by the Cumberland Carbon Company. The Cumberland Valley Gas and Refining Company also reports that there is approximately 1,500,000 cubic feet of natural gas used in and around Williamsburg each month for domestic purposes and that they have now approximately 3,000,000 cubic feet of gas available each day for manufacturing and domestic consumption. However, this company is drilling new wells and hope to have a production of 20,000,000 cubic feet per day within the next few months.

At Whitewood, Ky., is located the plant of the Natural Gas Products Company, which consumes about 8,000,000 cubic feet of gas per day.

In addition to the above, there is being built at the present time by some substantial people and under the supervision of Mr. G. A. Williams of the Liberty Carbon Company, a large plant in eastern Kentucky. The company erecting this plant is known as the Midas Carbon Company and the plant will consist of three units of twenty-eight single condenser buildings each.

The Petroleum Exploration Company, of Lexington, is also building a plant at Ida May, in Lee County, but it is not yet in operation.

In regard to the future development of this industry within the state it would seem that carbon black plants should only be established in those portions of Kentucky where the gas produced could not be economically utilized otherwise because natural gas should first, last and always be conserved as much as possible for utilization as a domestic and industrial fuel.

The Industrial Utilization of Limestone

Limestone is used for many purposes, among which may be mentioned as a building stone, as a fertilizer, for the production of lime, in the manufacture of cement, as a road material and as railroad ballast. All of these uses find application in Kentucky so that it may be said that most of the limestone quarried in the state finds use within her borders.

According to the United States Geological Survey Kentucky, with 66 plants, produced and sold in the year 1921, 2,260 tons of limestone of a value of $7,830 for rough constructional building purposes; 118,100 cubic feet of a value of $165,540 of rough architectural and dressed building stone; 4,080 tons of rabble of a value of $6,150; 790,720 tons of stone of a value of $988,753 for concrete and road metal; 695,320 tons of a value of $552,404 for railroad ballast; 13,070 tons of a value of $18,048 for agricultural purposes and a small amount for riprap and furnace flux, bringing the total limestone produced and sold up to 1,523,890 tons of an aggregate value of $1,755,505. The above does not include the limestone burned into lime or made into cement.

The utilization of limestone as a building stone has been previously mentioned. The possibilities of its use, when ground, as a fertilizer, are good, the quality of a great deal of the limestone in the state being excellent for this purpose, the drawback at the present time being the differential between cost of production and preparation and the selling price.

Jillson gives the production of lime, which is made by burning or calcining limestone, in Kentucky in 1920 as 1,757 tons of a value of $18,063. There seems to be room for a considerable development here.

As far as the manufacture of cement is concerned there is now one big cement company operating in the state, the Kosmos Portland Cement Company of Louisville. This company makes Kosmos Portland cement and Kosmortar (a special cement for masons). Their plant has a capacity of 12,000 sacks of cement and 4,000 sacks of Kosmortar daily in the manufacture of which about 250,000 tons of limestone and 40,000 tons of clay, all of which is quarried or excavated in Kentucky, are used per year. This shows what can be done in this regard.

So far as the utilization of crushed limestone as a road material and ballast is concerned, this is very general, the common practice being to open up a small quarry with the requisite crushing and screening apparatus near where the crushed stone is to be used and thus supply the local need for this material with a minimum of transportation cost. However, as has been noted, there are several large quarries, among which may be mentioned that at Tyrone on the Kentucky river near Lawrenceburg which operates on a sufficiently large scale to be able not only to use their product locally but also to ship it away.

It seems certain that the development of the limestone deposits of the state has kept pace with the demand and that there it little room for expansion, save, probably, in the case of building stone and cement, without a comparable increase in demand. The supply is present and it can be easily and cheaply obtained, therefore the demand will regulate production.

The Industral Utilization of Fluorspar

The industrial uses of fluorspar have been given, one of the principal ones being as that of a flux in the steel industry. Though there are a few steel plants in the state, at Ashland and Newport, nevertheless the greatest possible consumption of fluorspar at these plants would not be very much, so that it may be said that practically all the fluorspar mined in the state finds industrial utilization outside of Kentucky, and this will probably be the case until Kentucky establishes an iron and steel industry of some considerable size. A glass-making industry, which might very well be established within the state, as will be shown later, would also add to the internal consumption of fluorspar.

However, production statistics from 1896 to and including June, the first half of the year 1920, together with a list of the active and inactive fluorspar mines in 1920, with a list of the principal consumers in that year, should be of interest in showing where in the state production occurs and what industries, outside of the state, use the product, and also as tending to show along what lines economic development within the state will have to take place in order to utilize this resource internally. The data to be given have been abstracted from a paper entitled, "Production of Fluorspar in Western Kentucky," by W. R. Jillson, State Geologist, appearing in Economic Papers on Kentucky Geology, published by the Kentucky Geological Survey.

"The production (of fluorspar) in 1896 was 1,500 short tons, valued at $8,250. In 1903 this had risen to 30,835 tons, valued at $153,960. There followed then a depression culminating in 1908, when only 6,323 tons were produced. From this on there had been a gradual rise in production of fluorspar in Kentucky to 1918, when the peak tonnage of 87,604 tons was reached. (This was because of the war demand.) The tonnage for the first half of the year 1920 was 19,915 tons, valued at $493,880." This reduced tonnage was indicative of the slump in the steel market following the war. This slump was still being felt in 1921, when the United States Geological Survey gives the production as 15,266 short tons of a value of $294,513, though the normal reaction had started in 1922, when the production increased to 52,500 tons, as has been given previously. However, in 1921, the shipments from Kentucky exceeded those of Illinois for the first time since 1904.

LIST OF THE ACTIVE FLUORSPAR MINES IN KENTUCKY IN 1920.

1. Aluminum Ore Company, Mexico, Kentucky—Haffaw Mines.
2. American Fluorspar Company, Wheeling, West Virginia, and Salem, Ky.—Hudson Mine, Spar and Zinc.
3. Central Spar Mining Company, Marion, Kentucky—Gill.
4. Davis Mining Company, Hopkinsville, Kentucky—Mathews Mine.
5. Denny, O. S., Marion, Kentucky—Mine near Mexico, Kentucky.
6. Dixie Mining Company, Marion, Ky.—Corn Mine.
7. Eagle Fluorspar Company, Salem, Ky.—Hearne.
8. Eclipse Mining Co., Louisville, Ky.—Commodore Mine (lease expired).
9. Fairview Fluorspar and Lead Co., Marion, Ky.—Franklin Mine.

10. Frazer, Jim, Princeton, Ky.—Mine 6 miles north of Princeton.
11. Guggenheim Mining Co., Marion, Ky.—Lucille Mine.
12. Haynes, O. W., Marion, Ky.—Butler Mine.
13. Holly Ore and Mining Co., Marion, Ky.—Holly Mine.
14. Kentucky Fluorspar Co., Marion, Ky.—Brown Mine, Susie Beeler Mines, Yandell Mine, Pogue Mine, Mary Belle Mine.
15. Marion-Nashville Fluorspar Co., Marion, Ky.—Cox.
16. Mitchell, W. P., Marion, Ky.—Macer.
17. Myers and Cryder, Mexico, Ky.—Nancy Hanks.
18. National Fluorspar Co., Union City, Tenn.—Mitchell Mine.
19. Pope Brothers, Louisville, Ky.—Babb Mine, Livingston County.
20. Rawn, E. V., Hopkinsville, Ky.—Marble Mine.
21. Reed, A. H., Marion, Ky.—Big Four Mine, Macer, Fred Brown, Deer Creek Springs.
22. Royal Mining Co., New Orleans, La.—Spar, Zinc.
23. Southern Mineral Co., Mexico, Ky.—Pogue Mine, Paris Mine, Rider Farm.
24. Standard Spar Mining Co. of North America, Chicago, Ill., and Marion, Ky.—Eaton Mine, Keystone Mine.
25. Stribling, E. G., Marion, Ky.—Hardin or Red Fox Mine.
26. United Mining Co., Canton, Ohio and Lola, Ky.—Bonanza Mine.
27. U. S. Fluorspar Co., Marion, Ky.—K. K. Mine.
28. West Kentucky Ore Co., Marion, Ky.—Tabb Mine, Larue Mine.
29. White Fluorspar Co., Marion, Ky.—Glendale Mine.
30. Zinc Spar Mining Co., Marion, Ky.—Ebbie Hodge Mine.

LIST OF INACTIVE FLUORSPAR MINES.

1. Aluminum Ore Co., Mexico, Ky.—Memphis and Klondike Mines.
2. Clay Lick Fluorspar Co., Marion, Ky.—Davenport.
3. Clay Lick Fluorspar Co., Marion, Ky.—Redd.
4. Commodore Fluorspar Co., Hopkinsville, Ky.
5. Commodore Mining Co., Louisville, Ky.—Commodore Mine leased to Haynes and Clark.
6. Crittenden County Lead, Zinc and Fluorspar Co., Marion, Ky.—Butler Mine leased to C. W. Haynes.
7. Crosson Cave Mining Co., Marion, Ky.—Crosson Mine.
8. Denny, O. S., Marion, Ky.—Eva Tanguay Mine.
9. Farris Fluorspar Co., Paducah, Ky.—Porter Mine.
10. Farris Co., Paducah, Ky.
11. Farris and Shemwell, Paducah, Ky.—Bateman Mine.
12. Frazer, Jim, Princeton, Ky.
13. Haynes and Clark, Marion, Ky.—Commodore and Eclipse Mines.
14. Hill, D. B., Hopkinsville, Ky.—Edwards Mine.
15. K. K. Mining Co., Marion, Ky.—Property leased to U. S. Fluorspar Co.
16. Ken-See Mining Co., and O. K Oil Co., affiliated companies.

17. Kentucky Fluorspar Co., Ada Florence Mine, Beard Mine, Corn Mine, Susie Beeler Mine, Wheatcroft Mine.
18. La Grange Mining Co., Marion, Ky.—Ebbie Hodge Mine.
19. Mineral Ridge Mining Co., Paducah, Ky.
20. Myers and Crider, Mexico, Ky.—John Hodge Mine.
21. National Fluorspar Co., Union City, Tenn.—Johnson Mine.
22. North American Lead and Fluorspar Corporation, Smithland, Ky. —Klondike Mine and Royal Mine.
23. Pasco Mining Co., Marion, Ky.
24. Phelps and Hazlip, Paducah, Ky.—John Hodge Mine leased to Myers and Crider.
25. Pope Mining Co., Louisville, Ky.—Pope Mine.
26. Pope Mining Co., Louisville, Ky.—Watson Mine.
27. Reed, A. H., Marion, Ky.—Deer Creek Mine.
28. Roberts Fluorspar Co., Marion, Ky.—Tabor and Ashbridge Mines.
29. Tennessee Mining Co., Nashville, Tenn.—Ben Belt Mine.
30. White Fluorspar Co., Marion, Ky.—Reiter Mine.

LIST OF THE PRINCIPAL ACID FLUORSPAR CONSUMERS PURCHASING IN THE WESTERN KENTUCKY FIELD IN 1920.

1. General Chemical Co., Pittsburgh, Pa.
2. John C. Wiarda, Brooklyn, N. Y.
3. Aluminum Ore Co., East St. Louis, Ill.
4. E. J. Lavine, Philadelphia, Pa.
5. Mathew Eddy, Chicago, Ill.
6. National Enameling Co., Cleveland, Ohio.
7. Ball Bros., Muncie, Ind.

LIST OF THE PRINCIPAL STEEL INDUSTRIES PURCHASING FLUORSPAR IN 1920 FOR PURPOSES OF FLUX.

1. United States Steel Corporation, Pittsburgh, Pa.
2. Illinois Steel Corporation, Chicago, Ill.
3. Bethlehem Steel Corporation, Bethlehem, Pa.

In addition the following addenda should be noted as given by the United States Geological Survey for the year 1921.

The Ohio-Kentucky Fluorspar and Lead Corporation has taken over the Klondike and Royal mines near Smithland. The Tabb and Wheeler mines, near Mexico, were acquired late in 1921 from the West Kentucky Ore Company by the Kentucky Fluorspar Company. It is reported that several small operators abandoned the western Kentucky field entirely during 1921, leaving their workings to fill with water and their shafts to cave in, thus losing all development work done during the last few years.

The Clay Working Industry

As has already been noted, the clays of Kentucky are, perhaps, utilized in the manufacturing industry within the state more than any other of Kentucky's mineral resources. The products manufactured include common, rough texture, pressed and paving brick, hollow blocks, flue linings, floor, wall and roofing tile, chimney tops, fire brick and other refractory shapes, red earthenware, stoneware and art pottery. In most cases the clays utilized in the several factories come from near the plant, only a few manufacturers buying clays from outside the state.

The clay working plants of Kentucky are widely scattered throughout the state, perhaps the most important locality being Jefferson County, partly because it contains large deposits of excellent clays and partly because of the diversity of the products manufactured in and around Louisville. These include common and face brick, hollow blocks, flue lining, sewer pipe, drain tile, red earthenware, stoneware, imitation white ware and fire brick. While some of these plants operate entirely on clays obtained in Jefferson County, others get their raw material partly from the fire clay district of eastern Kentucky and partly from the fire clay district of Indiana.

In the following paragraphs will be given a brief resume of the clay working industry within the state:

At Albany, in Clinton County, is located a plant for the manufacture of common brick. This plant is operated by R. L. Sloan and the product is sold locally, principally.

At Ashbyburg, in Hopkins County, the Clark Manufacturing Company operates a plant making common brick drain tile and hollow block. This plant is equipped with three circular kilns, 26 to 28 feet in diameter, and the product finds a somewhat local market.

At Ashland, in Boyd County, are located the two plants of the Ashland Fire Brick Company, the larger one being equipped with twelve circular kilns and having a daily capacity of 40,000 brick while the smaller plant can produce 20,000 brick a day. As the name indicates the products made are regular and special fire brick. This is one of the largest fire brick establishments in Kentucky, and Mr. E. M. Weinfurtner, treasurer of the company, states that "Our product is manufactured exclusively of

Kentucky's natural resources, even including the coal used for fuel. Our fire clays consist of flint and semi-flint and plastic clays, of which the following is the approximate yearly consumption: Flint and semi-flint, 95,000 tons; plastic, 10,000 tons, making a total of 105,000 tons.'' At the same place, J. J. Cates and Company operate a plant for the manufacture of common brick.

At Barbourville, in Knox County, common brick, largely for local consumption, are made by the Barbourville Brick Company.

At Bell City, in Graves County, Mr. W. D. Russell operates a small plant for the manufacture of stoneware, most of the production being absorbed locally.

At Bellefonte, in Boyd County, The Means and Russell Iron Company manufactures common brick.

At Bybee, in Madison County, is located one of the most interesting of all the clay working plants in Kentucky. Here the Bybee Pottery Company manufactures a distinctive grade of hand-made blue art pottery which is not only sold locally but finds a ready market throughout the United States and Canada. At the same place Walter Cornelison operates a plant for the production of common brick and drain tile.

At Campbellsville, in Taylor County, common brick is being made, largely for local consumption, by the Russell Creek Association.

At Carrollton, in Carroll County, the Carrollton Brick Company makes common brick also largely for local use.

At Central City, in Muhlenberg County, the Central City Brick Company operates two Dutch kilns in which they manufacture dry pressed common brick for local consumption.

At Clinton, in Hickman County, common brick for use in the city are made by J. A. Harpole.

At Cloverport, in Breckinridge County, the Murray Roofing Tile Company manufactures roofing tile and red floor tile. This company owns and operates six circular kilns, 30 feet in diameter, making a plant of some size.

At Columbus, in Hickman County, common brick, chiefly for local use, are made by Thomas Boardman.

At Coral Ridge, in Jefferson County, near Louisville, the Clay Products Company has a plant of considerable size. This company operates five circular and five rectangular kilns in which they manufacture common brick, hollow block and fire brick.

At Covington, in Kenton County, four clay working plants are in operation. The Busse Brick Company and Broering and Merer both make common brick from local clays. The Cambridge Tile Manufacturing Company operates two plants at this point. This company makes a ceramic tile, both wall and floor, plain white and of different colors. They also make a specialty of various styles of figures and letters for signs and bulletin boards. The products of these plants has a large sale and is well and favorably known, but most of the clay used as a raw material comes from other states, though a rather small amount is obtained from the Purchase region of Kentucky.

At Firebrick, in Lewis County, the Peebles Paving Brick Company is operating a good sized plant, consisting of six circular and four rectangular kilns for the manufacture of common brick, rough texture brick and paving brick.

At Glasgow, in Barren County, common brick, for the local trade, are being made by the Dickenson Brick and Tile Company.

At Grahn, in Carter County, are located the two plants of the Louisville Fire Brick Works. These plants manufacture regular and special shapes of fire brick exclusively and are among the large plants of the state. The two plants together utilize fifteen circular kilns and have a daily capacity of 60,000 nine inch brick.

Two other large plants manufacturing fire brick are located at Haldeman, in Rowan County. Both these plants are owned and operated by the Kentucky Fire Brick Company, there being thirteen kilns at the number one plant and eleven at the number two plant, the daily capacity of the former being 40,000 brick and of the latter 35,000 brick.

At Hayward, in Carter County, the Ashland Fire Brick Company operates another large plant for the manufacture of special and regular fire brick, this plant having a daily capacity of 25,000 brick.

At Hazel Green, in Wolfe County, drain tile are being manufactured by the Hazel Green Brick and Tile Works.

At Henderson, in Henderson County, the Kleymeyer and Klutey Brick and Tile Works are in operation. This company owns and operates two plants, one for the manufacture of common brick and one for the manufacture of tile. The latter plant was established in 1880 and uses three circular kilns. The brick works are equipped with two Dutch kilns and two rectangular kilns, the latter having a capacity of 130,000 brick each.

Another of the large fire brick plants in the eastern part of the state is located at Hitchens, in Carter County, where the General Refractories Company operates sixteen circular kilns with a daily capacity of 75,000 brick.

At Hopkinsville, in Christian County, the Dalton Brothers Brick Company manufactures common brick and drain tile for use in the vicinity.

At Lebanon, in Marion County, the Goodwin Brick and Tile Company has a small plant consisting of one circular kiln where common brick and drain tile are made.

At Lexington, in Fayette County, common brick are made for local consumption from clay found in the vicinity by the Lexington Brick Company.

As has been stated before, Louisville, in Jefferson County, is a center for the clay working industry, several plants manufacturing various clay products being located at this point. One of the largest companies operating here is the P. Bannon Pipe Company with two plants. One of these plants produces sewer pipe, flue linings and chimney tops, the raw material coming in part from local sources, in part being fire clay from Soldiers, in Carter County, and in part coming from the fire clay fields near Duff, Indiana. This plant is equipped with twelve circular kilns. The other plant, equipped with fifteen circular kilns, produces common brick and fire brick, the fire clay coming from Carter County. Another large plant located at Louisville is that of the Louisville Fire Brick Works. This company manufactures standard fire brick of different grades, locomotive blocks, rotary kiln brick, stove backs, etc., the clay used coming partly from Grahn, in Carter County, and partly from Huntington, Indiana. This plant is equipped with sixteen circular kilns and has a

daily capacity of 50,000 nine-inch brick. The Louisville Pottery Company produces stoneware, imitation whiteware, red earthenware and flower pots, the first two products mentioned being manufactured from Indiana clays. This company operates five circular kilns and its product finds a market in all the central states. In addition to the three plants mentioned, the Progress Brick Company makes common and front brick.

At Maceo, in Daviess County, common brick is manufactured by the Maceo Brick and Tile Works. This brick is used chiefly in the local market.

At Madisonville, in Hopkins County, W. L. Hall manufactures common brick, face brick and low grade fire brick for the local market, while the Hall Tile Works makes hollow block. In addition the Madisonville Drain Tile Company, equipped with two circular kilns, produces drain tile and hollow block.

At Mayfield, in Graves County, the Standard Brick Company operates a good-sized plant. This plant is equipped with five circular and one rectangular kiln and produces common brick.

At Maysville, in Mason County, are located two large brick plants producing common brick. The Maysville Brick Company has a daily capacity of about 40,000 brick, while the Spahr Brick Company operates seven rectangular kilns, and, in addition to common brick, manufactures rough texture and pressed brick.

At McCall, in Greenup County, the Charles Taylor Sons Company operates a large fire brick plant. This plant is equipped with six circular and three square kilns, the daily capacity of the plant being 40,000 brick.

At Mentor, in Campbell County, the Busse Brick Company operates a plant producing common brick for local consumption.

At Moseleyville, in Daviess County, near Owensboro, the Clark Manufacturing Company operates a plant equipped with three circular kilns. This company reports that in 1922 they used 800 tons of clay for the manufacture of silo, drain and building tile, the cost value of this material being $38.46 per ton.

At New Haven, in Nelson County, the Nelson Brick and Tile Company operates a small plant for the manufacture of common brick and drain tile.

At Newport, in Campbell County, is located the plant of the Alhambra Art Tile Company. This company manufactures plain, embossed and dull finished enamel tile, terra vitrea, and faience tile. The raw material used is a mixture of clays, most of which are obtained from the H. C. Spinks Clay Company, which operates mines at Puryear, Tennessee. This product finds a wide market over the United States.

At Nicholasville, in Jessamine County, A. H. Schneider manufactures common brick for the local trade.

Two of the largest fire brick plants in the state are located at Olive Hill, in Carter County. These are the plants of the Harbison-Walker Refractories Company and that of the General Refractories Company. The former produces fire brick for blast and open hearth furnaces, locomotive backs, etc., and is equipped with sixteen circular kilns, having a daily capacity of 60,000 brick. The latter manufactures fire brick for various purposes and is equipped with twenty-seven circular kilns with a daily capacity of 90,000 brick.

At Owensboro, in Daviess County, the Owensboro Sewer Pipe Company manufactures flue linings, sewer pipe, etc. This plant is equipped with ten circular kilns having a daily capacity of 3,000 eight-inch sewer pipe, the product finding a wide market in cities from New Orleans to Cincinnati. In 1922 this company used 11,700 tons of Kentucky clay. S. B. McCullough also manufactures common brick for local use at this point.

At Paducah, in McCracken County, are located three clay working plants. The Paducah Pottery Company, utilizing some Indiana clay, makes stoneware. The Hill and Karnes Brick Company and the Paducah Brick and Tile Company both manufacture common brick, which find a market in western Kentucky and Tennessee chiefly.

At Pottertown, in Calloway County, Followell and Son operate a small plant which produces stoneware such as crocks, jugs, urns, etc., for local consumption.

At Providence, in Webster County, common brick is made, chiefly for the local market, by the Providence Brick Company.

At Salt Lick, in Bath County, a small plant for the production of common brick and tile is operated by the W. M. Karrick Brick and Tile Company.

At Sebree, in Webster County, U. S. Bishop and Sons with two 30-foot circular kilns, are manufacturing common brick, hollow block and drain tile.

At Stanton, in Powell County, a small plant for the manufacture of common brick is being operated by Atkinson and Baker.

At Sturgis, in Union County, the Quinwin Brick and Tile Company operates two circular kilns for the production of common brick, hollow block and drain tile.

At Uniontown, in Union County, the plant of Alhern and Waller, equipped with one circular and one rectangular kiln, makes drain tile up to twelve inches in diameter.

At Waco, in Madison County, near Bybee, is the plant of the Waco Pottery Company. This company manufactures stoneware, crocks, jugs, bowls and blue glazed art pottery similar to that made at Bybee. At the same place Grinstead and Stone make common brick and drain tile.

At West Point, in Hardin County, the West Point Brick Company, with six circular 32-foot diameter kilns, are manufacturing common and rough texture brick for sale throughout the state.

At Whitners, in Jefferson County, near Louisville, are located the two plants of the Southern Brick and Tile Company. One of these plants is equipped with five Dutch kilns and produces common brick, the other with one circular kiln and makes drain tile.

At Woodbine, in Whitley County, the Corbin Brick Company, equipped with four circular 30-foot diameter kilns, are making common and rough texture brick.

In addition, it should be mentionued that some clay, though not much in the aggregate, mined in Kentucky, is finding its way outside of the state for manufacture, two of the instances being (1), in the case of the American Clay Company, of Muncie, Indiana, which company has several openings near Wickliffe, in Ballard County, which clay they are using in glass pot manufacture, and (2), in the case of the Ironton Fire Brick Company, who are mining fire clay at Enterprise, in Carter County, for manufacture into fire brick at Ironton, Ohio.

While no attempt has been made in the foregoing to balance the yearly production of clay in the state with the yearly consumption, nevertheless the data given show that practically all the clay mined in Kentucky is manufactured within the state. Indeed, there is a certain amount of clay imported for special purposes, notably Indiana fire clay to Louisville and Tennessee clay to Newport. Manifestly all of the finished product is not consumed within the state, although a large part of the common brick made probably finds such a market, but the development of the clay mining industry has been followed by the development of the clay working industry, or, it may be, the other way round, which is quite as it should be, for the industrial wellbeing of the Commonwealth, and this will also undoubtedly continue to be the case in the future.

The Industrial Utilization of Rock Asphalt

One of the greatest national movements of the past few years has been that for good roads, and one of the most important prerequisites for a good road is a good surfacing material. While other states have been experimenting with various surfacings, Kentucky has developed, from her own resources, a new, practical and economical sort of road which is surfaced with asphaltic rock, one of her own natural mineral resources. As Jillson says (W. R. Jillson, "Kentucky Rock Asphalt," Economic Papers on Kentucky Geology, Kentucky Geological Survey): "The use of Kentucky asphalt rock as an ideal road material has gone forward in the last few years so quietly and satisfactorily that few people will believe that it is today being used as a pavement and rendering excellent service throughout many states, and in this state, in the cities, and country vicinities of Louisville, Lexington, Hopkinsville, Louisa, Lawrenceburg, Bardstown, Elizabethtown, Covington, Middlesboro, Pineville, Harlan, Corbin, Barbourville, Bowling Green, Versailles, Frankfort and Winchester."

Of all the road material used in the United States, asphalt is by far the most popular. The reasons for this popularity are many, but relative cheapness, noiselessness, appearance and ease of construction and repair are probably the outstanding virtues. The widespread use of imported asphalt as a road sur-

facing material has, however, been considerably restricted by its relatively high cost, which term includes relative cost plus maintenance. Ordinarily imported asphalt requires mixing with sand and other material in especially constructed machines, with a certain amount of heating, and it must be hot while being transferred. The required subsurface is also very costly, and, added to this, work of repairing must always be carried out along lines parallel to the original expensive construction.

The "Kentucky Rock Asphalt" pavement, using the commercialized or trade name, eliminates all of these above enumerated drawbacks associated with the construction of the ordinary asphalt road. And in addition to a saving of time and trouble, the most important consideration is that a road built of Kentucky Rock Asphalt costs less than any of the other high class pavements.

Kentucky Rock Asphalt as a commercial product comes from the quarry thoroughly mixed in correct proportions. It is laid without heating in ordinary temperatures by common labor, and no particular machinery is required except that used in making the ordinary limestone road. Repairs, when necessary, are just as simple and inexpensive. Kentucky Rock Asphalt is laid on an ordinary base of hard sandstone, slag, limestone, granite, concrete or brick, and is leveled with rakes by common labor. An ordinary ten-ton roller used in preparing the broken stone base may also be used for the surface. There are no extra materials to be added to the top of Kentucky Rock Asphalt, and as soon as it is rolled under ordinary temperatures it is ready for use.

Should a depression occur in the foundation, or should repairs have to be made following excavation of one kind or another, it is only necessary to restore the foundation to its proper height, cut a rectangular hole in the surface, and fill in with Kentucky Rock Asphalt. This should then be rolled, but if the opening has been very small, the traffic may be relied upon to compact it sufficiently.

As to the durability of this material and its ability to stand up under actual usage, the following examples may be given: In Buffalo, N. Y., the first rock asphalt pavement was laid in 1891 and this pavement, after the lapse of better than thirty years,

is still in use. In Ohio, the Nelson Avenue experimental road was laid in 1909. This road is composed of seventeen different types of pavement, and the Kentucky Rock Asphalt section is still in use, in excellent condition, and has had no repairs. In addition, a section taken from the Columbus experimental road and tested in 1919 by the Pittsburg Testing Laboratories, showed that after ten years' use as a road surfacing material, it still contained 7.42% of bitumen. This shows that the asphalt binder in Kentucky Rock Asphalt, after being exposed for ten years, was still present in the original, necessary proportions, thus establishing beyond a doubt the indestructible qualities of this material.

As has been stated, there is only one company in Kentucky producing rock asphalt to any appreciable amount at this time, though the prospects for the future development of other deposits seem bright. This is the Kentucky Rock Asphalt Company, with mines at Kyrock and offices at Louisville. Mr. W. L. Caldwell, president of the company, states that in the coming year this company expects to produce 150,000 tons of this material of an approximate value of $1,200,000. A comparison of this figure with those given below will show the remarkable strides made by this industry in the past few years.

In 1918 the production of rock asphalt, according to Jillson, was 3,194 tons of a value of $30,343; in 1919, 32,050 tons of a value of $304,475, and in 1920, 58,507 tons of a value of $555,-816.50.

The Industrial Utilization of Sandstone

In regard to this material it is manifestly impossible to enumerate all of the quarries from which sandstone has been produced for local use. Therefore, the general figures for 1921 as given by the United States Geological Survey should be of interest. Kentucky, with five plants operating, produced and sold in that year, 88,940 cubic feet of rough architectural and dressed building stone of a total value of $86,244; 31,690 tons of riprap of a value of $20,738, and small amounts of stone for rough construction, rubble, road metal and concrete, bringing the total for that year to approximately 49,860 tons of an aggregate value of $121,982.

However, there are three companies which may be mentioned, all operating in Rowan County, whose product is not only used locally, but without the state as well.

The largest of these is the Rowan County Freestone Company, located at Farmers. Mr. H. Van Antwerp, general manager of this company, gives the following information concerning its activities: "We produce here sawed building stone, which is marketed very largely outside our own state, seventy-five per cent of our output going to New York City and vicinity and twenty-five per cent being sold more locally. Most of it is building stone, and is used for trimming—perhaps half of the seventy-five per cent being in the form of window sills alone. We produce quite a bit of 2-inch, 2½-inch and 3-inch flagging, such stone constituting probably twenty per cent of our output.

"The cubic foot is the unit of measurement and we ship approximately 200 car loads in a normal season, or 60,000 cubic feet, with a valuation of around $50,000.

"As a quarry by-product, we ship perhaps 150 cars of riprap per annum, sold by the ton and of low value, probably 7,500 net tons at 70c is $5,250.

"The supply of available stone is inexhaustible, but the market is limited and probably well met now, unless new uses are developed, which might easily be done."

The Kentucky Bluestone Company, at Bluestone postoffice in Rowan County, produce stone burial vaults as a special line and probably ship of these and of building stone, 120 to 130 car loads per year, with a money valuation of around 40,000 dollars. They also ship, as a by-product, around 75 car loads of riprap per annum.

The Blue Grass Quarries Company, also located at Bluestone postoffice, are rather small producers, shipping material probably not to exceed a yearly value of $10,000.

Special note should be taken of Mr. Van Antwerp's remark that the present market is probably well supplied, but that new uses for this material could be easily developed, thus giving promise of future expansion in this industry.

The Industrial Utilization of Phosphate Rock

Although the phosphate rock or "rotten stone" deposits of Kentucky cover quite an area in the central part of the state, nevertheless there is only one company operating on this material. This is the United Phosphate and Chemical Company, situated near Midway, which is the local postoffice, with the main office at Richmond, Va., whose product, after proper preparation, is shipped to points both in and out of the state for use as an agricultural fertilizer. The future development of this resource will probably depend on the making and maintaining of an adequate market.

The Industrial Utilization of Mineral Pigments and Barytes

As has been stated, a number of mineral resources of Kentucky, though large, perhaps, in amount, have not as yet been developed to any great extent. This is true of both mineral pigments and barytes.

So far as known to the writer there are no major industrial plants in Kentucky using either of these natural resources as raw materials, a condition which the future will undoubtedly remedy.

Industral Utilization of Mineral Waters

Mention has been made of the fact that several of the mineral springs of Kentucky have been commercialized to the extent of having had resorts built up around them where people may go and take advantage of the medicinal properties of the waters. However, the industrial utilization of these waters is largely, if not entirely, limited to this. Nevertheless, there would seem to be some opportunity for further development along the lines of either bottling and selling the waters as such or else evaporating them, thus obtaining the essential salts, and selling these.

Probably no great industry could be built up along these lines, but the point is worthy of mention.

The Industrial Utilization of Sands

As has been pointed out the sands of Kentucky can be used for various purposes, such as in the manufacture of glass, for

molding purposes and for building use. Indeed, a great tonnage of this material is being used annually within the state for these purposes.

The United States Geological Survey gives the following data on the amount and value of the sand produced in Kentucky and used in the different industries for the year 1921. There were 42,861 tons of molding sand of a value of $52,656 produced; 409,027 tons of building sand of a value of $370,748; 10,615 tons of engine sand of a value of $8,440; 44,842 tons of paving sand of a value of $39,759; and small amounts of glass sands, grinding and polishing sands, fire or furnace sands and filter sands, bringing the total to 524,205 tons of an aggregate value of $496,707. In regard to gravel, there were 288,633 tons of paving gravel produced with a value of $154,106; 286,671 tons of railroad ballast of a value of $92,190; with small amounts of building and roofing gravel, bringing the total of gravel of all kinds to 832,307 tons of an aggregate value of $466,877.

Glass Manufacture

There is a considerable amount of sand being mined each year in Kentucky which is used in the manufacture of glass, but unfortunately, not in this state, the sand being shipped to West Virginia, Ohio, Indiana, or some other state for this purpose. This fact is not to the credit of Kentucky, for Richardson, in Glass Sands of Kentucky, says, ''Kentucky is exceedingly fortunate:

''(1) In possessing an inexhaustible supply of most excellent glass sand either for the manufacture of glass within the state or for shipment to other states.

''(2) In containing within her borders limestone and calcite of high degree of purity to be used as flux in the treatment of the sands.

''(3) In possessing an abundance of natural gas which is the ideal fuel in the glass industry, coal from which producer gas can be manufactured, and petroleum which is often used as a fuel.

"(4) In having fluorspar in abundance which is equal in purity to any spar in America and which is required in the manufacture of certain kinds of glass."

With Kentucky's wonderful deposits of glass sands and with the availability of cheap fuel for the purpose of manufacture, there seems no reason why a great glass industry should not be established in the Commonwealth.

As far as the use of Kentucky sand for molding is concerned it may be said that quite a considerable amount is thus being used annually in foundries, steel works and brick plants both locally and outside of the state. In this respect it may be of interest to note that the only one of Kentucky's natural resources that is being used by the Ashland Steel Company of Ashland is "ganister stone" which is used to the approximate yearly value of $2,500. This stone is a siliceous material and may be classified among the sands and sandstones.

The utilization of sand for building purposes, for the making of cement, plaster and concrete is, of course, widespread throughout the state, most of the sand used for these purposes coming from Kentucky and some being exported to points outside her boundaries. A compilation of the companies using sand in this way would include practically all those in all the cities, towns and hamlets of the state using this material. Let the statement suffice that essentially all the sand used for the ordinary purposes of building within the state comes from within Kentucky.

The Industrial Utilization of Building Stone

Mention has been made that there are many limestone and sandstone quarries in the state, most of which are being operated on a comparatively small scale in order to furnish stone for local consumption. Reference under sandstone has also been made to the freestone development at Farmers and Bluestone in Rowan County. In addition to these special mention should be made of the quarries at Bowling Green, which are producing oolitic limestone similar to the Bedford lime of Indiana. This stone has been used locally for some time and maintains a most excellent resistance to weathering. The principal producing companies are the Bowling Green Quarries Company of Bowling Green and the Caden Stone Company of Hadley, though there

are a few other producers who sell mostly for local use and do not operate regularly. The production of this stone in Warren County in 1921 was 117,000 cubic feet of rough and dressed building stone of a value of $145,790; 11,000 cubic feet of rough and dressed monumental stone of a value of $24,750; and 6,230 tons of other stone of a value of $5,840, making a total production for that year of approximately 16,800 short tons of a value of $176,380. However, in spite of this production, Indiana, in the same year, imported into Kentucky, limestone of no better grade than that produced near Bowling Green to the amount of 70,704 cubic feet. One reason for this was the difference in freight rates, but it seems an anomaly that limestone should be brought into the state from Indiana when stone of the same grade or better can be and is being produced at home.

The Industrial Utilization of Calcite

At the present time there are no major industries within Kentucky utilizing Kentucky calcite as a raw material. Indeed, very little, if any, of this substance is being mined within the state.

Mention has previously been made of the great calcite vein in Mercer County. This vein in the past has been worked at its outcrop on the Kentucky river by the Chinn Mineral Company, and later by the Heyward Mineral Company, and a few analyses of the calcite found here may be of interest and value.

Analysis of pulverized calcite from the Chinn Mineral Co. with plant at Munday's Landing:

Moisture	00.01
Ignition, CO_2	44.01
Silica, SiO_2	00.10
Alumina, Al_2O_3	00.00
Ferric Oxide, Fe_2O_3	00.11
Lime, CaO	55.43
Magnesia, MgO	00.77
Sulphuric Anhydride, SO_3	00.00
Total	100.43

The above analysis would give calcium carbonate as 98.82 and the magnesium carbonate as 1.61. Analysis by J. S. McHargue.

Analysis number two. Sample, about five pounds of the very fine, nearly white powder. Analysis of the air dried sample.

Moisture	trace
Ignition	42.66
Silica, SiO_2	00.37
Alumina, Al_2O_3	00.16
Ferric Oxide, Fe_2O_3	00.08
Calcium Oxide, CaO	53.50
Magnesium Oxide, MgO	00.74
Barium Sulfate, $BaSO_4$	2.30
Total	99.81

Calcium carbonate, $CaCO_3$, equivalent to the CaO is 95.49.

Magnesium carbonate, $MgCO_3$, equivalent to MgO is 1.58.

The iron is in the ferrous condition, as ferrous carbonate. Analysis by S. D. Averitt.

Analysis number three. Sample, 14½ ounces of milky calcite in small pieces. A little adhering limestone; a very little sphalerite, ZnS, some barite in streaks in the calcite and a 38 gram lump of barite equivalent to 7% of the sample.

Moisture	trace
Ignition	40.50
Silica, SiO_2	00.10
Alumina, Al_2O_3	00.14
Ferric Oxide, Fe_2O_3	00.11
Calcium Oxide, CaO	49.78
Magnesium Oxide, MgO	00.65
Barium Sulfate, $BaSO_4$	9.12
Total	100.40

$CaCO_3$ equivalent to the CaO is 88.84. $MgCO_3$ equivalent to the MgO 1.39. Most of the iron is in the ferrous condition as ferrous carbonate, in the sample. Analysis by S. D. Averitt.

In view of the above it seems apparent that there is room for further economic development of this resource.

The Industrial Utilization of Ochre and Iron Ore

Neither of these natural resources of the state are being produced in Kentucky at the present time so far as the writer has been able to determine, therefore, to say that they are finding no industrial use within the state is superfluous.

In regard to ochre, there is doubtless some room for the economic development of this resource, though it will probably not be great.

As far as iron ore is concerned there is, as has been pointed out, a big future in the state, not only for the iron mining industry, but also for the iron and steel industry as well. At the present time there are three steel plants in Kentucky, The Ashland Steel Company at Ashland, the American Rolling Mills Company, which is now engaged in a $10,000,000 expansion program at Ashland, and the Andrews Steel Company at Newport, all of which obtain their iron ore outside the state. In addition there is a blast furnace for the production of pig iron at Middlesboro, but this furnace is not now in operation. Nevertheless, the United States Geological Survey gives the production of pig iron in Kentucky in 1921 as 28,375 tons of a value of $816,372, and in 1922 as 140,217 tons of a value of $2,951,627, or an increase in quantity of 394% in one year.

If then, right now, Kentucky can compete with other states in the production of iron and steel, both using Lake Superior ore, how much more will she, with her inexhaustible supplies of coking coal, be able to do so when the time comes, as come it will, when the grade of ore produced in the Lake Superior district has dropped to such a figure that it will pay to mine Kentucky's own deposits of ore. Then may be anticipated an iron and steel development within the state which is not dreamed of at the present time.

The Industrial Utilization of Lead and Zinc

As has been indicated previously, the lead and zinc of Kentucky occur in connection with the fluorspar deposits in the western part of the state. Indeed, the lead and zinc concentrates are recovered as by-products in the concentration of the fluorspar. The production of these metals in 1921, according to the United States Geological Survey, was very nominal, being 69 tons of lead of a value of $6,210 and 220 tons of zinc of a value of $22,000. As far as the silver content of the galena of this district is concerned the same authority states: "The galena recovered is argentiferous, the silver content varying from a very small quantity to more than three ounces per ton, but no recovery of this silver has been reported by the smelters during the last ten years." The average lead content of the galena concentrates in 1920 and 1921 was 71%, the total value of the lead and zinc concen-

trates shipped from Kentucky mines having been $23,493 in 1921 as against $13,045 in 1920.

The principal seller of galena concentrate in 1921 was the Kentucky Fluorspar Company, though the American Spar Company operated the Hudson mine of the Eagle Fluorspar Company near Salem, in Livingston County, for part of the year.

However, at this writing, there are no metallurgical plants in Kentucky treating the lead and zinc ores mined within the state, whatever ores that are so mined being treated in other states. It seems probable that there is no future development of any size to be expected along this line as, even with a greatly increased production within the state, it would be cheaper to ship the raw material to already established smelting plants in Missouri and Illinois rather than to establish the smelters in Kentucky.

The Industrial Utilization of Oil Shale

Right now there are no plants for the industrial utilization of oil shale in Kentucky, nor, indeed, of any size at least, in the United States as a whole. However, there are several companies doing preliminary work, as has been mentioned, among these being the Central Shale Oil Corporation of Pittsburg, with property about eight miles east of Mt. Sterling, in Montgomery County. In addition it may be said that any company mining oil shale within the state practically always must, of economic necessity, manufacture its oil and by-products at or close to its mines and will generally refine the oil produced close to the same point. This means that not only will Kentucky profit through the mining of this material, but also that a great manufacturing industry will spring up in connection with it, the one, of necessity, keeping pace with the other, so that, within the next one or two decades, we may look forward to the establishment of a large industry within the state which will utilize resources at the present time untouched.

The Industrial Utilization of Water Power

Mention has been made in the preceding pages of the hydroelectric development now under way on the Dix river and of the proposed harnessing of the Cumberland river around Burnside

and at the falls of the Cumberland. These are straws indicating the direction of the wind and it would not be surprising to see more of Kentucky's latent water power developed in the not far distant future.

Conclusion

In the light of the facts brought out in the preceding pages we can now venture to answer the questions previously propounded with a greater degree of assurance.

Has Kentucky "became great" through the industrial utilization of her natural mineral resources? Yes and no. In some respects, surely, in others, not at all.

That she has become great, up to the limit of her possibilities, in the utilization of her crude oil there can be no question. That she has become great in the commercial exploitation of her coal and fluorspar is equally true but surely not as great as she can and will become on either of these counts, more especially the former. Kentucky's clays are partially developed and, fortunately, their industrial utilization within the state has kept fair pace with this development, but there is room for much greater activity. Her sands are used locally, it is true, but where is her glass industry? Somewhere in the future. And of the rest not much can be said.

Kentucky's industrial greatness in the utilization of her natural mineral resources except as shown is, unfortunately, a near greatness, in comparison with the natural wealth with which she has been so plenteously endowed. Indeed, much of the greatness that she does enjoy has been "thrust upon" her by capital from outside the state.

However, that the citizens of the great Commonwealth of Kentucky will allow her wonderful endowment of natural mineral resources to lie dormant indefinitely is not to be seriously considered. Even now they are awakening to the potentialities lying waiting for the magic wand of capital to transfer them into actualities. Such being true, is it too much to hope that comparatively soon, in the course of a few decades, more or less, it can be said that not only was Kentucky born gloriously great, but also that industrial greatness, through utilization of her natural mineral resources, has come upon her, and not entirely

through the use of outside capital but largely through the faith of her own people in her future as one of the great industrial states of the Union.

In the following pages will be found a directory of manufacturing firms within the state which use Kentucky's natural mineral resources as raw material. It would be manifestly impossible to show all the users of Kentucky's coal and gas, from a fuel standpoint, and no effort has been made to do this. Neither are the different mines or quarries in the state listed as they are not, in general, manufacturing concerns. In certain cases, as where a quarrying company also works its stone up into finished building stone or similar instances, the enterprise is included. The fluorspar mines are listed in the body of the report but do not belong in the directory. Also there are thousands of building contractors, small foundaries, etc., which are using Kentucky sand for various purposes. A directory of these would include practically everyone so engaged within the state and would serve no useful purpose, therefore it has not been attempted. However, those of Kentucky's mineral springs which have been commercialized by having resorts built up around them, have been included.

Every effort has been made by the writer to include in the following directory every firm in the state which is using any of Kentucky's natural mineral resources, excluding coal and gas for fuel, either wholly or in part, as a raw material or materials and he believes that he has done so, with the exceptions before noted. If any firm has been left out which should have been included, it has been through inadvertence or through failure to obtain the correct data entirely, and the writer hereby apologizes before the fact.

The directory has been arranged alphabetically by cities and towns with the sub-heading being, first, the name of the firm, second, the product or products of the manufacturing operation, third, those of Kentucky's natural mineral resources used, and fourth, remarks.

Directory of the Manufacturing Enterprises in Kentucky which Utilize Kentucky's Natural and Mineral Resources as Raw Materials.

ALBANY, CLINTON COUNTY.

R. L. Sloan—Common Brick, Clay.

ASHBYBURG, HOPKINS COUNTY.

Clark Manufacturing Company—Brick and Tile, Clay.

ASHLAND, BOYD COUNTY.

American Rolling Mill Company—Sheet Steel and Iron; Coal, Sand, Limestone.

Ashland By-Product Coke Company—Metallurgical Coke, Coal.

Ashland Fire Brick Company—Fire Brick, Fire Clay.

Ashland Steel Company—Steel, Ganister (Sandstone).

J. J. Gates and Company—Common Brick, Clay.

BARBOURVILLE, KNOX COUNTY.

Barbourville Brick Company—Common Brick, Clay.

BELL CITY, GRAVES COUNTY.

W. D. Russell—Stoneware, Clay.

BELLEFONTE, BOYD COUNTY.

Means and Russell Iron Company—Common Brick, Clay.

BENHAM, HARLAN COUNTY.

Wisconsin Steel Company—Bee Hive Coke, Coal.

BLUESTONE, ROWAN COUNTY.

Kentucky Bluestone Company—Burial Vaults, Building Stone; Freestone.

Bluegrass Quarries Company—Building Stone, Freestone (Sandstone).

BOWLING GREEN, WARREN COUNTY.

Bluegrass Quarries Company—Building Stone, Limestone.

Park City Refining Company—Refinery Products, Petroleum.

Riggs Refining and Pipe Line Co.—Refinery Products, Petroleum.

Ulf Brothers—Refinery Products, Petroleum.

BURKESVILLE, CUMBERLAND COUNTY.

Cumberland County Refining Co.—Refinery Products, Petroleum.

BYBEE, MADISON COUNTY.

Walter Cornelison—Brick and Tile, Clay.

Bybee Pottery Company—Art Pottery, Clay.

CAMPBELLSVILLE, TAYLOR COUNTY.

Green River Oil and Gas Company—Carbon Black, Natural Gas.

Russell Creek Association—Common Brick, Clay.

CAMPTON JUNCTION, POWELL COUNTY.

Neha Refining Company—Refinery Products, Petroleum, Office, Lexington.

CANNEL CITY, MORGAN COUNTY.

Collier Oil and Gas Company—Natural Gas Gasoline, Natural Gas.

CARROLLTON, CARROLL, COUNTY.

Carrollton Brick Company—Common Brick, Clay.

CENTRAL CITY, MUHLENBERG COUNTY.

Central City Brick Company—Common Brick, Clay.

CHARLESTON, WEST VIRGINIA.

Columbia Gas and Electric Company—Office, Plant at Leach, Boyd County, Ky., Natural Gas Gasoline, Natural Gas.

Cumberland Carbon Black Company (Mr. Oscar Nelson)—Office, Plant at Williamsburg, Whitley County, Ky., Carbon Black, Natural Gas.

Eastern Carbon Black Company (Davis Brothers)—Office, Plant in Floyd County, Ky., Carbon Black, Natural Gas.

Menifee Gasoline Corporation—Office, Plant at Chambers, Menifee County, Ky., Natural Gas Gasoline, Natural Gas.

Natural Gas Products Company (Mr. Oscar Nelson)—Office, Plant at Whitewood, Green County, Ky., Carbon Black, Natural Gas.

CHAMBERS, MENIFEE COUNTY.

Menifee Gasoline Corporation—Office, Charleston, West Virginia, Natural Gas Gasoline, Natural Gas.

CLARKSBURG, WEST VIRGINIA.

Liberty Carbon Black Company (Mr. G. A. Williams)—Office, Plant in Floyd County, Ky., Carbon Black, Natural Gas.

Mr. G. A. Williams—New Carbon Black Plant in Eastern Kentucky.

Mr. Lynn S. Horner—Office, Plant near Greensburg, Ky., Carbon Black, Natural Gas.

CLEVELAND, OHIO.

Cumberland Gasoline Corporation—Office, Plant at Fixer, Lee County, Ky., Natural Gas Gasoline, Natural Gas.

CLINTON, HICKMAN COUNTY.

J. A. Harpole, Common Brick, Clay.

CLOVERPORT, BRECKINRIDGE COUNTY.

Murray Roofing Tile Company—Tile, Clay.

COLUMBUS, HICKMAN COUNTY.

Thomas Boardman—Common Brick, Clay.

CORAL RIDGE, JEFFERSON COUNTY.

Coral Ridge Clay Products Company, Office, Louisville—Brick and Tile, Clay.

COVINGTON, KENTON COUNTY.

Broering and Merer—Common Brick, Clay.

Busse Brick Company—Common Brick, Clay.

Cambridge Tile Manufacturing Company—Tile, Clay. Some from Kentucky and some from elsewhere, two plants.

Petroleum Refining Company—Refinery Products, Petroleum.

CRAB ORCHARD, LINCOLN COUNTY.

Crab Orchard Springs—Mineral Waters, Mineral Waters.

CREELSBORO, RUSSELL COUNTY.

Carnahan Oil and Refining Company—Refinery Products, Petroleum.

DAWSON SPRINGS, HOPKINS COUNTY.

Dawson Springs—Mineral Water, Mineral Water.

DRY RIDGE, GRANT COUNTY.

Carlsbad Springs—Mineral Waters, Mineral Waters.

FARMERS, ROWAN COUNTY.

Rowan County Freestone Company—Building Stone, Freestone (Sandstone).

FIREBRICK, LEWIS COUNTY.

Peebles Paving Brick Company—Brick, Clay.

FIXER, LEE COUNTY.

Cumberland Gasoline Corporation—Natural Gas Gasoline, Natural Gas. Formerly Mississippi Valley Oil Co., Office, Cleveland, Ohio.

FLOYD COUNTY.

Eastern Carbon Black Company, Carbon Black, Natural Gas, Office, Charleston, West Virginia (Davis Bro.),

Liberty Carbon Black Company, Office, Clarksburg, West Virginia (Mr. G. A. Williams). Carbon Black, Natural Gas.

FRANKLIN, SIMPSON COUNTY.

Western Kentucky Refining Co.—Refinery Products, Petroleum.

GLASGOW, BARREN COUNTY.

Dickenson Brick and Tile Company—Common Brick, Clay.

GRAHN, CARTER COUNTY.

Louisville Fire Brick Works, Two Plants—Fire Brick, Fire Clay.

GRAVEL SWITCH, LIVINGSTON COUNTY.

Illinois Central Railroad—Ballast, Gravel.

HADLEY, WARREN COUNTY.

Caden Stone Company—Building Stone, Limestone.

HALDEMAN, ROWAN COUNTY.

Kentucky Fire Brick Company, Two Plants—Fire Brick, Fire Clay.

HAYWARD, CARTER COUNTY.

Ashland Fire Brick Company—Fire Brick, Fire Clay.

HAZEL GREEN, WOLFE COUNTY.

Hazel Green Brick and Tile Works—Tile, Clay.

HENDERSON, HENDERSON COUNTY.

Kleymeyer and Klutey Brick and Tile Works, Two Plants—Brick and Tile, Clay.

HITCHENS, CARTER COUNTY.

General Refractories Company—Fire Brick, Fire Clay.

HOPKINSVILLE, CHRISTIAN COUNTY.

Dalton Brothers Brick Company—Common Brick and Tile, Clay.

IDA MAY, LEE COUNTY.

Petroleum Exploration Company—Carbon Black, Natural Gas. Office, Lexington. New plant under construction.

IRVINE, ESTILL COUNTY.

Estill Springs—Mineral Waters, Mineral Waters.

KYROCK, EDMONSON COUNTY.

Kentucky Rock Asphalt Company, Office at Louisville—Road Material, Rock Asphalt.

LEACH, BOYD COUNTY.

Great Eastern Refining Company—Refinery Products, Petroleum.

Columbia Gas and Electric Company, Office, Charleston, West Virginia—Natural Gas Gasoline, Natural Gas.

LEBANON, MARION COUNTY.

Goodwin Brick and Tile Company—Brick and Tile, Clay.

LEXINGTON, FAYETTE COUNTY.

Central Kentucky Natural Gas Company, Executive Office, Oil City, Pa.—Natural Gas, Natural Gas.

Great Southern Refining Co.—Refinery Products, Petroleum.

Lexington Brick Company—Common Brick, Clay.

Neha Refining Company, Office, Refinery at Campton Junction, Powell County.

Old Kentucky Refining Company—Refinery Products, Petroleum.

Petroleum Exploration Company, Office, Plant under construction at Ida May, Lee County—Carbon Black, Natural Gas.

Superior Oil Company. Office, Plant above Torrent in Wolfe County, Natural Gas Gasoline, Natural Gas.

LOUISVILLE, JEFFERSON COUNTY.

Coral Ridge Clay Products Company, Office, Plant at Coral Ridge, Jefferson County—Brick and Tile, Clay.

Kosmos Portland Cement Company—Portland Cement and Kosmortor, Limestone and Clay.

Kentucky Rock Asphalt Company, Office, Plant at Kyrock, Edmonson County—Road Material, Rock Asphalt.

Louisa Company of Kentucky, Successor to Aetna Refining Company—Refinery Products, Petroleum.

Louisville Fire Brick Works—Fire Brick, Clay, partly from Kentucky and partly from Indiana.

Louisville Gas and Electric Company—Natural Gas, Natural Gas. Natural Gas Gasoline Plant at Winchester, Clark County.

Louisville Pottery Company—Stoneware, Earthenware, etc.; Clay, partly from Kentucky, partly from Indiana.

P. Bannon Pipe Company—Sewer Pipe, etc.—Clay.

P. Bannon Pipe Company, Plant, No. 2—Fire Brick, Fire Clay, partly from Kentucky, partly from Indiana.

Progress Brick Company—Common Brick, Clay.

Southern Brick and Tile Company, Office. Plant at Whitners, Jefferson County, Brick and Tile, Clay.

Standard Oil Company of Kentucky—Refinery Products, Petroleum; partly from Kentucky, partly from other states.

Stoll Oil Refining Company—Refinery Products, Petroleum.

MACEO, DAVIESS COUNTY.

Maceo Brick and Tile Works—Common Brick, Clay.

MADISONVILLE, HOPKINS COUNTY.

Hall Tile Works—Hollow Block, Clay.

Madisonville Drain Tile Company—Drain Tile and Hollow Block, Clay.

W. L. Hall—Common Brick, Fire Brick, Clay.

MAYFIELD, GRAVES COUNTY.

Standard Brick Company—Common Brick, Clay.

MAYSVILLE, MASON COUNTY.

Maysville Brick Company—Common Brick, Clay.
Spahr Brick Company—Common Brick, Clay.

McCALL, GREENUP COUNTY.

Charles Taylor's Sons Company—Fire Brick, Fire Clay.

MENTOR, CAMPBELL COUNTY.

Busse Brick Company—Common Brick, Clay.

MIDWAY, WOODFORD COUNTY.

United Phosphate and Chemical Company, Office, Richmond, West Virginia—Fertilizer, Phosphate Rock.

MONTICELLO, WAYNE COUNTY.

Woodford Oil Company, Office, Plant at Oil Valley, Wayne County—Natural Gas Gasoline, Natural Gas.

MOSLEYVILLE, DAVIESS COUNTY

Clark Manufacturing Company, Post Office Address, R. R. No. 3, Owensboro, Ky.—Common Brick, Hollow Block, Drain Tile; Clay.

MUNDAY'S LANDING, JESSAMINE COUNTY.

Heyward Mineral Company—Calcite, Calcite. Successor to Chinn Mineral Company. Not in operation at present time.

NEW HAVEN, NELSON COUNTY.

Nelson Brick and Tile Company—Common Brick, Drain Tile; Clay.

NEWPORT, CAMPBELL COUNTY.

Alhambra Tile Company—Various Sorts of Art Tile, Clay, partly from Kentucky but mostly from Tennessee.

NICHOLASVILLE, JESSAMINE COUNTY.

A. H. Schneider—Common Brick, Clay.
Heyward Mineral Company, Office. Plant at Munday's Landing, Jessamine County, Calcite. Successor to Chinn Mineral Co. Not in operation at the present time.

OIL CITY, PA.

Central Kentucky Natural Gas Company, Executive Offices, Natural Gas. Corporate Offices at Lexington, Ky.

OIL VALLEY, WAYNE COUNTY.

Wood Oil Company—Natural Gas Gasoline, Natural Gas. Office at Monticello, Wayne County.

OLIVE HILL, CARTER COUNTY.

General Refractories Company—Fire Brick, Fire Clay and Sand.

Harbison Walker Refractories Company—Fire Brick, Fire Clay.

OLYMPIA SPRINGS, BATH COUNTY.

Olympia Springs—Mineral Waters, Mineral Waters.

OWENSBORO, DAVIESS COUNTY.

Clark Manufacturing Company, Post Office Address R. R. No. 3. Plant at Mosleyville, Daviess County—Common Brick, Hollow Block, Drain Tile; Clay.

Owensboro Gas Company—Gas and Coke, Coal.

Owensboro Sewer Pipe Company—Sewer Pipe, etc.; Clay.

S. B. McCullough—Common Brick, Clay.

PADUCAH, McCRACKEN COUNTY.

Hill and Karnes Brick Company—Common Brick, Clay.

Paducah Brick and Tile Company—Common Brick, Clay.

Paducah Pottery Company—Stoneware, Clay, partly from Kentucky, partly from Indiana.

PAINTSVILLE, JOHNSON COUNTY.

Big Sandy Oil and Refining Co.—Refinery Products, Petroleum.

PINE HILL, ROCKCASTLE COUNTY.

Rockcastle Portland Cement and Lime Company—Lime, etc.; Limestone.

POTTER TOWN, CALLOWAY COUNTY.

Folwell and Son—Stoneware, Clay. Post Office Address, Almo.

PROVIDENCE, WEBSTER COUNTY.

Providence Brick Company—Common Brick, Clay.

PRYSE, ESTILL COUNTY.

Great Southern Refining Company—Refinery Products, Petroleum. Office at Lexington.

RICHMOND, VIRGINIA.

United Phosphate and Chemical Company, Office. Plant at Midway, Woodford County, Ky.—Fertilizer, Phosphate Rock.

SALT LICK, BATH COUNTY.

W. M. Karrick Brick and Tile Company—Common Brick and Drain Tile, Clay.

SCOTTSVILLE, ALLEN COUNTY.

Massie Refining Company—Refinery Products, Petroleum.

SEBREE, WEBSTER COUNTY.

U. S. Bishop and Sons—Common Brick, Hollow Block, Drain Tile; Clay.

STANTON, POWELL COUNTY.

Atkinson and Baker—Common Brick, Clay.

STURGIS, UNION COUNTY.

Quinwin Brick and Tile Company—Common Brick, Hollow Block, Drain Tile; Clay.

TORRENT, WOLFE COUNTY.

Superior Oil Company—Natural Gas Gasoline, Natural Gas. This plant is north of Torrent. Office at Lexington.

UNIONTOWN, UNION COUNTY.

Alhorn and Waller—Drain Tile, Clay.

WACO, MADISON COUNTY.

Gristead and Stone—Common Brick, Drain Tile; Clay.

Waco Pottery Company—Stoneware, Blue Art Pottery; Clay.

WEST POINT, HARDIN COUNTY.

West Point Brick Company—Common Brick, Clay.

WHITEWOOD, GREEN COUNTY.

Natural Gas Products Company—Natural Gas Gasoline, Natural Gas. Office, Charleston, West Virginia (Mr. Oscar Nelson).

WHITNERS, JEFFERSON COUNTY.

Southern Brick and Tile Company, Two Plants—Common Brick, Drain Tile; Clay. Office, Louisville.

WILDIE, ROCKCASTLE COUNTY.

Rockcastle Freestone Company—Building Stone, Freestone.

WILLIAMSBURG, WHITLEY COUNTY.

Cumberland Carbon Black Company—Carbon Black, Natural Gas. Office, Charleston, West Virginia.

Cumberland Valley Gas and Refining Company—Natural Gas, Natural Gas. Formerly Iriquois Oil and Gas Company.

WINCHESTER, CLARK COUNTY.

Louisville Gas and Electric Company—Natural Gas Gasoline, Natural Gas. Main Office, Louisville.

WOODBINE, WHITLEY COUNTY.

Corbin Brick Company—Common Brick, Clay.

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BIBLIOGRAPHY.

1. Census Reports on Kentucky, 1920. United States Bureau of the Census.
2. Davis, D. H. Geography of the Jackson Purchase. Kentucky Geological Survey, Series 6, 1922.
3. Foerste, A. F. The Silurian, Devonian and Irvine Formations of East Central Kentucky. Kentucky Geological Survey, Bulletin No. 7, 1906.
4. Jillson, W. R. Kentucky Rock Asphalt. Economic Papers on Kentucky Geology. Kentucky Geological Survey, Series 6, 1921.
5. Jillson, W. R. Recent Mineral Production in Kentucky. The Sixth Geological Survey. Kentucky Geological Survey, Series 6, 1921.
6. Jillson, W. R. Production of Fluorspar in Western Kentucky. Economic Papers on Kentucky Geology. Kentucky Geological Survey, Series 6, 1921.
7. Jillson, W. R. Geological Research in Kentucky. Kentucky Geological Survey, Series 6, Vol. XV, 1923.
8. Jillson, W. R. Conservation of Natural Gas in Kentucky. John P. Morton and Co., Louisville, 1922.
9. Kentucky Geological Survey, Series 4, Vol. 1, 1913.
10. Richardson, C. H. Glass Sands of Kentucky. Kentucky Geological Survey, Series 6, 1920.
11. Ries, Heinrich. Clays of Kentucky. Kentucky Geological Survey, Series 6, 1922.
12. Ries, Heinrich. Economic Geology.
13. United States Geological Survey. Mineral Resources of the United States.

VII.

GEOLOGY OF JEPTHA KNOB

By Walter H. Bucher

Assistant Geologist

INTRODUCTION

Jeptha Knob is an isolated hill in eastern Shelby County, Kentucky. With an elevation of 1176 feet, it rises over three hundred feet above the low divides of the fertile plain which extends from the latitude of Louisville eastward beyond Lexington and Maysville and is commonly known as the "Blue Grass region." The northern foothills of the Knob touch the "Midland Trail" at Clay Village, about 37 miles east-southeast of Louisville and 7 miles east-southeast of Shelbyville, almost exactly half way between Louisville and Lexington. The Southern Railroad curves around it on the southwest and south sides. The nearest station is Hemp Ridge, 47 miles from Louisville by rail. A small patch of Silurian marks its location on the geological map of Kentucky.[1]

The view from the cleared top of the Knob is quite unique, with the fertile plain studded with prosperous farms extending to the level horizon on all sides. There is no point, however, from which the whole view can be enjoyed simultaneously. The top is too flat. An inexpensive steel tower would soon form a center of attraction for local people as well as for tourists, provided the only road leading up to the top were improved. This "Knob road" at present is practically inaccessible to automobiles. To the south of the highest point it is practically impassible even to buggies down almost to the foot of the hill on the south side.

Over thirty miles away from the "Knob country," in its isolation Jeptha Knob suggests rather an old volcano than a "butte-temoin," a lone witness of the former extension of the strata now flanking the Jessamine dome. The peculiar problems it offers were well recognized by Linney in his report on

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[1] Revised edition, 1920. Ky. Geol. Survey, Ser. VI. (Scale 1:633600.)

Shelby County. He wrote: "The reason of this remarkable preservation, as in other analogous cases, lies in the fact that there was, in the uplift of the foundations of the state, a more extraordinary disturbance of the rocks in the immediate vicinity of this elevation than took place over the surrounding country. Several fractures, extending to great depths, took place in all the rocks, and they dropped down or were pushed up in these places, leaving a basin-like depression by which the surrounding surfaces were, for a while, protected against erosion. They have long since lost that protection, and are now being rapidly eroded."[2] He also clearly recognized that "these fractures are local, hardly affecting a line much greater than the base of the Knob." (p. 14.)

The great quantities of chert which cover the top of the Knob in such remarkable fashion, and "which may be found in so many fields over the surrounding country, and filling the beds of the small branches extending from it," he considered as "merely the hard parts of layers of stone now in place near the top, but once extended over the whole surface of the county" (p. 14), "the broken fragments of the Corniferous hornstone." (p. 11.)

The purpose of this report is to give a detailed description of the stratigraphy, structure, and topography of the Knob and by the observations here recorded, to test these conclusions of Linney. It will be seen that while his observations were largely correct as far as they went, they were inadequate. The data here presented have led the writer to quite different views.

The chapters in this report are arranged in their logical order. The remarks on the physiographic interpretation of the Knob have been placed at the end of the paper instead of the beginning, as is customary. It is obvious that the physiographic history can be studied profitably only after the structure has been described, and a discussion of the structure is possible only with a knowledge of the stratigraphy.

[2] W. M. Linney, "Report on the Geology of Shelby County," Kentucky Geological Survey, 1889 (?), 16 pp. and map.

STRATIGRAPHY OF THE JEPTHA KNOB AREA

I. The Ordovician

a. *The Units Used in Mapping*

Exposures of the size and continuity required to define the boundaries of stratigraphic units with the precision customary in modern stratigraphic work, are lacking almost completely within the disturbed portion of the Jeptha Knob area. The larger upper part of the Ordovician section is seen only in a more or less strongly deformed condition which makes an accurate correlation of individual disconnected observations very difficult.

In the course of field work it soon became evident, therefore, that the attempt to distinguish on the map the units of the Ordovician section in their accepted definition, had to be abandoned. Only divisions based on fossil forms that are abundant, as well as characteristic, could be successful. A process of elimination gradually led to the following crude but useful division of the Ordovician rocks of the Jeptha Knob area.

Lower Division. Platystrophia and *Hebertella* in large and well preserved specimens absent or rare (excepting the upper ten feet).

1. *Dalmanella-Plectambonites Beds*

Aside from the *Rafinesquina* and *Zygospira*, which are present in all formations of the Ordovician, *Dalmanella* and *Plectambonites* are the only common brachiopods. *Dalmanella* is present throughout, *Plectambonites* only in the lower, larger portion. (Corresponds to the Eden formation and approximately the lower half of the Mt. Hope member of the Fairview formation.)

2. *Strophomena maysvillensis-Constellaria Beds*

In the lower half *Dalmanella* is as abundant as in the preceding beds it is absent in the upper half. *Strophomena maysvillensis* and *Constellaria* are present throughout, generally in abundance. (Corresponds to the upper half of the Mt. Hope and the Fairmount member of the Fairview formation.)

Upper Division. Platystrophia and *Hebertella* in large and well preserved specimens are present throughout, generally in large numbers, with the exception of the *Cyphotrypa* beds.

3. *Platystrophia-Hebertella Beds*

Both genera are represented throughout by numerous specimens which at many levels fairly crowd the beds. In the larger upper part, typical Richmond faunules occur at several horizons. (Corresponds to the McMillan and Arnheim formations.)

4. *Cyphotrypa Beds*

Differs lithologically from all other formations of this region. The characteristic globular bryozoan *Cyphotrypa clarksvillensis* and the elegant shells of *Lophospira bowdeni* are common at most levels. (Essentially equivalent to the Waynesville formation.)

5. *Upper Richmond Beds*

Filled with an abundance of species and specimens of the typical Richmond fauna. Only one form of *Platystrophia* was seen in contrast to the variety of species associated with the Richmond forms in the lower horizons. (Essentially equivalent to the Liberty formation.)

b. Detailed Stratigraphical Notes

1. *Dalmanella-Plectambonites Beds*

a. *The Cynthiana Formation*

At only one point, on the spur running south from the highest elevation of Jeptha Knob, at an approximate elevation of 1,000 feet, an undoubted outcrop of the Cynthiana formation was seen. There, in limestones of a thickness uncommon in the Eden, a typical specimen[3] of *Eridotrypa briareus* (Nicholson, was found associated with strongly convex specimens of *Rofinesquina alternata* (Emmons), several specimens of *Plectambonites* cf. sericeus (Sowerby), a small individual of *Cyclonema varicosum cincinnatiense* (Foerste), and the pygidium of a Proetus. The writer was unable to determine the structural relations of

[3] All Ordovician Bryozoans referred to in this paper were identified by Dr. Geo. Twitchell of Cincinnati to whom the writer wishes to express his sincere thanks.

this outcrop. Its high elevation suggests that other outcrops may lie concealed by the vegetation and the large quantities of residual chert covering the hillsides.

b. The Eden Formation

The Plectambonites-bearing divisions of the Eden formation outcrop only in the uplifted central portion of the Knob. Exposures are lacking almost entirely.

The limestones intercalated with the shale appear in the float as flat slabs. Much of the limestone is strongly crinoidal. *Plectambonites,* together with *Dalmanella,* is common, often covering the surfaces of the slabs. Bryozoans are inconspicuous on the whole. The best faunule, collected on the south side of the Knob in the "Knob road," comprises the following species:

Plectambonites sericeus (Sowerby).
Dalmanella multisecta (Meek).
Zygospira modesta Hall.
Amplexopora petasiformis (Nicholson).
Batostoma implicatum (Nicholson).
Dekayella ulrichi (Nicholson).
Hallopora onealli (James).

At two other localities *Batostoma jamesi* (Nicholson) was collected. At an elevation of about 960 feet, near the bottom of the valley which occupies the center of the north side of the Knob, the only fragments of *Trinucleus* were seen. Since *Trinucleus* is normally quite abundant in the lowest division of the Eden formation, its conspicuous absence over most of the central Eden outcrop of Jeptha Knob seems to indicate that on the whole these lowest beds do not come to the surface there.

c. The Uppermost Forty Feet

In the undisturbed region only the uppermost forty to fifty feet of the *Plectambonites-Dalmanella* beds outcrop, and these only in Jeptha Creek.

They exhibit the familiar intercalation of limestone layers and calcareous shale, the latter predominating. Many of the limestone layers are highly fossiliferous, the surfaces being covered with bryozoans and *Dalmanella.* An occasional bed consists largely of shells of *Rafinesquina* washed together. Many beds, on the other hand, are quite barren, dense bluish-gray lime-

stones with much fine sand, in most cases deserving to be called calcareous sandstone, or better, siltstone. Where weathering has removed the calcareous cement, they appear as buff or brown highly porous sandstones in which such fossils as are present appear as molds. Sandy layers of this type extend throughout the overlying *Strophomena maysvillensis-Constellaria* beds.

The fauna of these beds comprises the following species:

Dalmanella multisecta (Meek).
Rafinesquina alternata (Emmons).
†*Platystrophia sublaticosta* McEwan.
†*Platystrophia profundosulcata* (Meek) var. hopensis.
Zygospira cincinnatiensis Meek.
**Constellaria florida prominens* Ulrich.
Dekayella ulrichi (Nicholson).
Escharopora falciformis (Nicholson).
Hallopora dalei (Milne-Edwards and Haime)
Hallopora onealli var. *communis* (James).
Peronopora vera Ulrich.
Cyclonema mediale Ulrich.

2. *Strophomena maysvillensis-Constellaria Beds*

The presence of *Strophomena maysvillensis* is the outstanding characteristic of these beds. At most levels it is common, at many abundant. The same is true of *Constellaria*. Neither *Strophomena* nor *Constellaria* make their appearance at once in great numbers. They come in at first in scattered individuals. At the level where the first specimens are seen, *Plectorthis* also appears in considerable numbers, associated with a *Platystrophia* probably identical with *Pl. sublaticosta* (McEwan), and what seemed to be unusually large numbers of *Rafinesquina*. This peculiar assemblage of brachiopods seemed to be limited to a few feet and was used as a base of the *Strophomena maysvillensis* beds.

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*Constellaria was seen in only one specimen. For practical purposes it may be considered to be absent from these forty feet in contrast to the overlying beds.

†Platystrophia is regularly found at about an elevation of 720 ft., though only in scattered occasional specimens. It is practically absent from the rest of these beds up to the base of the Strophomena maysvillensis horizon. As long as detailed faunal studies on the upper Eden and Mount Hope beds of this region are lacking, definite judgment as to the stratigraphic correlation of these beds should be withheld, especially in view of the seeming absence of such a characteristic Fairview genus as Plectorthis. It seems probable, however, that they will be assigned to the Mount Hope member of the Fairview formation.

The physical character of these beds is similar to that of the underlying strata, the alternation of limestones and shales giving rise to the familiar miniature falls and ledges in all creeks. It is this alternation of resistant and non-resistant beds which insures good exposures wherever the streams have cut down to them. The limestones gradually increase in proportion to the shale so that in the upper half of the formation it equals or exceeds 50 per cent. Here the alternation of limestone layers a few inches thick with beds of shale of similar thickness reaches a high degree of regularity in many exposures.

Fig. 1. Typical exposure of upper part of Stroph. maysvillensis beds. West side of Jeptha Knob; north of Hooper Road.

The thickness of the *Strophomena maysvillensis* beds is 80 feet. Of these the lower half is characterized by the presence, mostly in abundance, of *Dalmanella multisecta,* which seems to be entirely absent from the upper half.

Through an oversight the writer failed to collect good bryozoan material in the lower half of these beds. In addition to the brachiopods mentioned above, *Rafinesquina squamula* (James) and *Plectorthis fissicosta* (Hall) were collected.

Several faunules collected within ten to twenty feet from the top of these beds, consist of the following forms:

Rafinesquina alternata (Emmons).
Strophomena maysvillensis Foerste.
Zygospira modesta Hall.
Batostoma sp.
Constellaria florida Ulrich.
Hallopora dalei (Milne-Edwards and Haime).
Heterotrypa frondosa (d'Orb).
Homotrypa curvata Ulrich.
Homotrypa flabellaris spinifera Bassler.
Monticulipora mammulata (d'Orbigny).
Peranopora vera Ulrich.

In the uppermost five to ten feet a fairly large *Platystrophia* and *Hebertella* occur in scattered individuals associated with *Strophomena maysvillensis* and Fairview bryozoans.

The faunal change to the *Platystrophia-Hebertella* beds is sharp. Since the overlying beds at least in their lower portion contain almost no shale, they are generally poorly exposed and their base more or less clearly forms a spring horizon. While the contact itself is exposed only at few places, its location can generally be determined with considerably accuracy without much difficulty.

3. *Platystrophia-Hebertella Beds*

a. *The Bellevue Member*

Where sufficiently exposed, the basal 30 feet of the *Platystrophia-Hebertella* beds can readily be told by the almost complete absence of shale and the conspicuous cross-bedding of the thin limestone beds which otherwise do not differ lithologically from the Cincinnatian type. The limestone abounds in well preserved specimens of *Platystrophia ponderosa* and *Hebertella occidentalis sinuata*. Of the bryozoans, *Hallopora ramosa* is common everywhere and *Monticulipora molesta* at least present. The following species were collected from these 30 feet at the base of the *Platystrophia-Hebertella* beds:

Hebertella occidentalis sinuata Hall.
Platystrophia ponderosa Foerste.
Platystrophia unicostata Cumings.
Platystrophia cf. foerstei McEwan.
Rafinesquina alternata (Emmons).
Rafinesquina alternata fracta (Meek).
Bythopora gracilis (Nicholson).

Ceramoporella chioensis (Nicholson).
Hallopora ramosa (d'Orbigny).
Heterotrypa frondosa (d'Orbigny).
Homotrypa obliqua Ulrich.
Monticulipora molesta Nicholson.

These beds clearly represent the Bellevue member of the McMillan formation of Bassler's nomenclature. They are well exposed within the limits of the map only north and northwest of the Midland Trail, in the creek beds and in a small abandoned quarry in the northwest corner of the map.

b. *The Higher Beds*

The higher beds are nowhere satisfactorily exposed in the undisturbed portion of the area and good exposures are rare in the disturbed part. No reliable measurements of thickness could therefore be made and only the general character of the stratigraphic section could be made out.

Fig. 2. Typical exposure of the ponderosa beds of the lower Arnheim formation, showing deep soil overlying the rubbly layers. South side of Jeptha Knob.

On the whole the beds overlying the Bellevue member are less regularly bedded, often even strongly rubbly in character, particularly where the large shells of *Platystrophia ponderosa* crowd the layers. Exposures of conspicuous shale layers are rare, but shale seems to be present in varying amounts, intercalated between the limestone. The latter is itself more argil-

laceous than the limestones of the earlier formations. It gives rise to unsually deep soil, generally cut by numerous gullies.

At or near the base of these higher beds, that is, about thirty feet above the base of the *Platystrophia-Hebertella* beds, a conspicuous coarse breccia occurs, consisting of more or less angular fragments of limestone of the ordinary Cincinnatian type, deposited together with abundant shells of *Platystrophia* and *Hebertella.* An extraordinary exposure of this breccia is found on the east side of the headwaters of Wolf Run at an elevation of about 1,000 feet (Fig. 3).

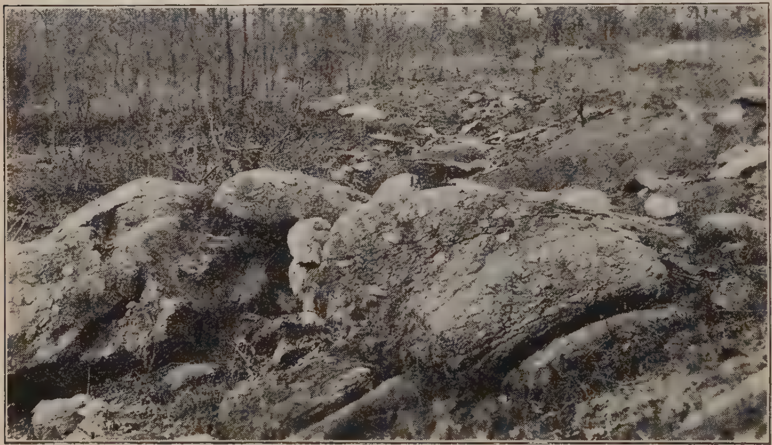

Fig. 3. Limestone breccia near the base of the Arnheim formation. Headwaters of Wolf Run.

An abundance of large shells of the *Platystrophia ponderosa* group and of *Hebertella occidentalis sinuata* characterize these beds everywhere. They occur in extraordinary quantities and in individuals of unusual size, especially in the lower half of these higher beds, through a thickness of some 50 or 60 feet of more or less rubbly limestone. At various levels beginning about 10 feet above their base, they are associated with *Leptaena richmondensis* and *Dalmanella meeki.*

Good exposures of these lower beds, in disturbed condition, are to be seen, for instance, north of the Midland Trail in the beds of the creek that flows through Clay Village. Numerous small exposures are found throughout the folded margin of the Jeptha Knob structure.

These lower "*ponderosa* beds" are followed by a middle section in which *Constellaria polystomella* is rather common. *Rhynchotrema dentata* was found associated with the *Constellaria* at several localities. *Platystrophia ponderosa,* while still common, is not as abundant as in the lower part, and other species, notably *Pl. cypha,* become conspicuous. These "*Constellaria* beds" consist of more evenly bedded, harder and more bluish-gray limestone which looks more like the Fairmount than any horizon since *Platystrophia ponderosa* made its appearance. Their thickness is estimated at 25 to 30 feet. The contact of the "*ponderosa* beds" and the "*Constellaria* beds" is well exposed in Britton Run, near "R" of the word "Run" on the map.

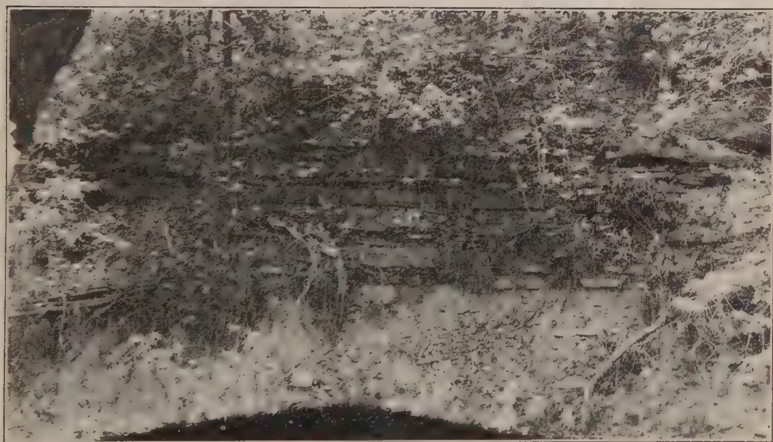

Fig. 4. Shaly beds of the upper Arnheim formation carrying Leptaena, Rhynchotrema capax and other Richmond forms, overlain by alternating limestones and shales with large Platystrophia and Hebertella. South bank of Britton Run.

The "*Constellaria* beds" seem to be overlain by a similar thickness of more irregularly bedded, often distinctly rubbly argillaceous limestone in which various forms of *Platystrophia,* together with *Hebertella* dominate.

In these upper beds especially, but locally much farther below, many of the species characteristic of the Liberty formation make their first appearance. The most conspicuous occurrence seems to be a horizon approximately 30 feet below the base of the overlying *Cyphotrypa beds.* Here not only *Streptelasma rusticum, Rhynchotrema capax, Strophomena planumbona* are found

in numbers, but also *Dinorthis subquadrata*. The most convincing locality for the study of this fauna and its relation to the *Cyphotrypa* beds, is the hill which rises to an elevation of 980 feet less than a mile southeast of Sleadd school.

The following species were identified in the whole of the Platystrophia-Hebertella beds above the Bellevue:

Dalmanella meeki (Miller).
Dinorthis subquadrata (Hall).
Hebertella occidentalis sinuata (Hall).
Leptaena richmondensis (Foerste).
Platystrophia clarksvillensis Foerste.
Platystrophia cumingsi McEwan.
Platystrophia cypha (James).
Platystrophia cypha (James), var. approaching *crassa* in form.
Platystrophia foerstei McEwan.
Platystrophia ponderosa Foerste.
Platystrophia sublaticosta McEwan.
Rafinesquina alternata (Emmons).
Rafinesquina cf. nasuta (Conrad).
Rhynchotrema capax (Conrad).
Rhynchotrema dentatum (Hall).
Strophomena planumbona (Hall).
Batostoma varians (James).*
Constellaria probably *polystomella* Nicholson.
Escharopora hilli James.
Eridotrypa simultatrix (Ulrich).
Hallopora subnodosa (Ulrich). (Some specimens which externally resemble *ramosa* may belong to that species.)
Hallopora sp. (resembling an undescribed form from the Middle Arnheim at Russellville, Ohio).[4]
Heterotrypa sp. (closely allied to *frondosa* but not identical; undescribed).
Streptelasma rusticum (Billings).
Protarea richmondensis Foerste.

The largest part of these higher Platystrophia-Hebertella beds clearly represent the Arnheim formation. The writer has been unable to recognize the Corryville and Mount Auburn members of the McMillan formation in the field and a study of the faunules collected seems to confirm their absence. It should be remembered, however, that within the area studied good continu-

[4]The writer is indebted to Dr. Geo. Twitchell for the identification of all bryozoans listed in this paper.

ous exposures permitting a consecutive collection of faunules are lacking. The Corryville and Mount Auburn members have been reported as being absent in the sections at Sulphur, Ky., about 25 miles north-northwest of Jeptha Knob, and at Madison, Ind., about 45 miles in the same direction.[5]

Detailed zonal analysis of the section at Madison has shown the presence there of over fifty feet of rock clearly to be classed as Corryville and Mount Auburn.[6]

If such an error is possible under excellent conditions of exposure, it may well have crept in where disturbed conditions prevail. In view of the perplexing question of the Ordovician-Silurian boundary, no statement concerning changes in thickness of these formations should be made in print until detailed faunal studies have been made between Madison and Jeptha Knob.

The division of the Arnheim formation into a lower half, the "*ponderosa* zone," and an upper half, with *Constellaria* and fewer individuals of *Platystrophia ponderosa,* agrees well with the condition in Jefferson County, as described by Butts (loc. cit.). The uppermost beds, here estimated at 30 feet, are transitional to the Waynesville formation and may well eventually be assigned to it,

The total thickness of the *Platystrophia-Hebertella* beds has been estimated at about 150 feet. It is probable that this estimate is too low rather than too high.

4. *The Cyphotrypa Beds*

The peculiar lithological character of the *Cyphotrypa* beds makes it possible for one not familiar with the details of our Ordovician faunas to follow in the field the major lines of the structure. They consist of thick beds of a very light-colored greenish-gray argillaceous limestone. Upon weathering they break up into large rounded blocks which are utterly different from any other rocks seen around Jeptha Knob. The *Cyphotrypa* beds are also the only formation of this region on which sinkholes have formed.

[5] Butts, Ch., "Geology and Mineral Resources of Jefferson County, Kentucky," Ky. Geolog. Surv., Ser. IV, Vol. 3, pt. 2, p. 69.
[6] McEwan, E. D., "The Ordovician of Madison, Indiana," Amer. Jour. Sci., Ser. 4, Vol. 50, 1920, pp. 154-159.

The contrast with the adjoining formations is no less marked when the fossil content is considered. Brachiopods are rare or absent in the average exposure, although occasional layers carry both *Platystrophia* and *Hebertella*. *Cyphotrypa clarksvillensis* is the only bryozoan that is seen in the average exposure. The hollow, more or less spherical bodies of this form are readily recognized in cross section as well as when weathered out. Besides *Cyphotrypa* only gastropods can be called common in these beds, among which the graceful spire of *Lophospira bowdeni* is seen most frequently. No identifiable specimens of other species of gastropods were obtained.

At or near the base of the *Cyphotrypa* beds a species of *Tetradium* was found at several localities, apparently representing the coral bed which is found at the base of this formation throughout Jefferson County.[7] The thickness of the *Cyphotrypa* beds seems to be about 40 feet.

The list of fossils identified in the Cyphotrypa beds follows:

Hebertella occidentalis sinuata (Hall).
Platystrophia annieana Foerste.
Platystrophia foerstei McEwan.
Strophomena planumbona (Hall).
Zygospira kentuckiensis James.
Cyphotrypa clarksvillensis Ulrich.
Lophospira bowdeni (Safford).
Streptelasma rusticum (Billings).
Tetradium sp.

These beds are identical with the Waynesville limestone of Butts' report on Jefferson County. Butts calls attention to the fact that the presence of *Cyphotrypa clarksvillensis* points to the conclusion that the Waynesville of Jefferson County corresponds to the upper division (Clarksville of Foerste) of the Waynesville of Ohio.

Breccias below nad above Cyphotrypa Beds

At three or four places within the area of the map a limestone breccia was observed within the *Platystrophia-Hebertella* beds below the *Cyphotrypa* beds. At one of these localities, on the extreme eastern spur of the Knob, the vertical distance be-

[7] Butts, Chas., loc. cit., p. 49.

tween the breccia layer and the base of the *Cyphotrypa* beds seems to be about 30 feet. At all points the breccia consisted of fragments of limestone enclosed in limestone of similar character, clearly deposited simultaneously with the matrix and the organic remains among which *Streptelasma rusticum* and *Strophomena planumbona* were noted particularly. There is no evidence at hand that these breccia beds represent the same horizon nor that any or all are continuous over most or all of the area.

The presence of *Streptelasma rusticum* distinguishes them from the breccia near the base of the Arnheim formation (as here interpreted). The same fossil is, however, equally conspicuous in a third breccia layer which was seen at no less than a dozen widely separated points within the Jeptha Knob area, either immediately overlying the *Cyphotrypa* beds or not many feet above them. The highly disturbed position of the beds at all points where this breccia was observed made it impossible to determine the stratigraphic relations accurately. This breccia is especially well exposed in the ''Knob road,'' on the south side of Jeptha Knob, where the narrow band of the Liberty beds crosses the road, and again at the eastern end of this band, where it forms huge blocks of unusually massive limestone. It is everywhere associated with the typical Liberty fauna.

5. *The Liberty Beds*

The change from the thick-bedded, argillaceous, quite unfossiliferous *Cyphotrypa* beds to the thin-bedded, hard limestones abounding in a wealth of species and specimens of easily recognized fossils is as striking as any in this region.

The total list of fossils identified in these beds follows:

Stromatocerium huronense (Billings).
Columnaria calicina (Nicholson).
Protarea richmondensis (Foerste).
Streptelasma rusticum (Billings).
Streptelasma divaricans (Nicholson).
Dinorthis subquadrata (Hall).
Hebertella occidentalis sinuata (Hall).
Leptaena richmondensis Foerste.
Platystrophia annieana Foerste.
Platystrophia cf. cypha (James).
Plectambonites rugosus (Meek).

Rafinesquina alternata (Emmons).
Rhynchotrema capax (Conrad).
Strophomena planumbona (Hall).
Strophomena planumbona subtenta (Hall).
Batostoma sp.
Bythopora meeki (James).
Rhombotrypa quadrata (Rominger).

The coarse breccia at or near the base of these Liberty beds was described above. While it was by no means seen everywhere above the *Cyphotrypa* beds, it seems probable that it was strongly developed over much of the Jeptha Knob area.

At the few places at which *Columnaria* was found, it occurred some distance, say at least five to ten feet above the breccia.

The top of the formation has been lost by erosion wherever the Liberty beds occur. Its total thickness can therefore not be determined.

The Liberty is the last formation involved in the strong disturbance that has affected the neighborhood of Jeptha Knob. All the older folded and faulted formations up to and including the Liberty beds, are overlain with a strong angular unconformity by nearly horizontal layers of more or less dolomitic limestone, which here are all referred to the Silurian system.

I. The Silurian

a. *Detailed Stratigraphical Notes*

1. *The Dolomitic Limestone*

The actual contact between the disturbed bluish-gray Ordovician rocks below and the buff or brownish level rocks above is, unfortunately, nowhere clearly exposed. In some places, where the more or less thick-bedded porous buff Silurian rocks rest on the impervious shales of the Eden and Fairview formations, slumping has carried the upper beds down below their normal level. This process can be seen in action near the head of the streams which flow directly west from Jeptha Knob. Here, on the north slope of the southwestern ridge of Jeptha Knob, huge blocks of the dolomitic limestone are seen in various stages of breaking off and moving down toward the creek bed.

A short distance downstream from this locality, a remnant of such a tumbled block is exposed in the path that follows the valley bottom, simulating with its N. 50° W. strike and a dip of 30° to 60° the attitude of the disturbed beds of the neighborhood.

On the south side of the ridge referred to above, slumping has carried the rock 50 to 60 feet below the normal level, where it now is seen exposed here and there along the foot-path or along the hillside, in seeming continuity with the normal beds above, showing steep and utterly inconsistent dips.

The most remarkable remnant of such a "slide" is preserved about half a mile south of the highest point of Jeptha Knob. Here, over a small space, without any relation to the surrounding structure, an excellent exposure shows the Silurian beds striking N. 30° E. to N. 70° E. and dipping from 30° to nearly 90°.

At first the writer was inclined to interpret such dipping Silurian beds as evidence of a later, probably post-Silurian period of deformation. But the areal relations of the outcrops as well as detailed observations in the field have convinced him that they are due merely to slumping.

On the whole the base of the Silurian rocks follows more or less the 1,060-foot contour line. At least at one point it lies decidedly higher, namely, on the spur extending south from the highest point of Jeptha Knob, where the barometer read 1,100 at the base of the Silurian. It would seem, therefore, that the base on which the dolomitic limestone of the Silurian was deposited, was uneven.

The distance from 1,060 feet to 1,176 feet, the highest point of Jeptha Knob, represents a total thickness of the Silurian rocks of 116 feet. Of these the uppermost portion consists of chert. The contact of the clearly secondary chert and the underlying beds varies from 1,120 to 1,150 feet. The greatest thickness of the beds below the chert is therefore at least 90 feet. They consist of dolomitic limestone and shale. In spite of variations, their petrographic character remains essentially the same throughout this thickness.

Much of the rock is buff or brownish, fine-grained, "silty" looking limestone which does not effervesce as immediately and voluminously with cold hydrochloric acid as does a pure lime-

stone. Some beds abound in minute little vugs lined with deep brown crystals of dolomite often incrusted with lustrous silica. Such layers generally show bands and irregular patches in which dolomite forms a crystalline mass, the individual crystals of which can easily be recognized with a hand lens. The calcite filling the interstices between the dolomite crystals is commonly recrystalized so as to display crystallographic units of considerable dimensions. When a hand specimen of such rock is turned, areas of interstitial calcite measuring an inch or more in diameter will reflect the light simultaneously. Some porous layers consist entirely of such coarser dolomitic texture.

Some beds contain crinoid joints, either few and scattered or in great numbers. In all cases that were tested by the writer, the crinoid joints consisted of calcite, even where the matrix was partly or wholly dolomitic.

In some beds other fossils are present. In such layers, besides fossils, fragments of rocks occur, giving the rock more or less the character of a breccia. In certain layers of porous coarse-grained dolomite angular fragments of yellowish and greenish shale abound. Weathering removes the shale and gives such rock surfaces an extremely rough, cavernous appearance.

The most interesting layers are, however, the breccias in which fragments of Ordovician and Brassfield limestones besides large quantities of Ordovician and Brassfield fossils lie embedded in a buff or yellowish matrix of normal Silurian dolomitic limestone or softer shaly rock.

While scattered blocks of the hard limestone breccia are seen at a number of places, it is nowhere exposed in situ. The steeply dipping beds of the landslide mass half a mile south of the highest point offers, however, a splendid opportunity to study this unusual rock.

The more shaly phase of this fossil breccia, on the other hand, is beautifully exposed at the narrow prong extending southwest from point 1,165 feet of the southwest spur of Jeptha Knob. The location is illustrated by figure 5. Here the coarser breccia can be seen grading into a finer-grained breccia with innumerable fragments of various fossils assorted by size.

These breccias clearly form local lenses in the normal beds of dolomitic limestone and shale rock. They do not seem to be

Fig. 5. View illustrating the unconformity at the base of the Silurian, showing the layers of fossil breccia in the basal Silurian overlying in horizontal position the dipping beds of the Eden formation. Southwest prong of hill 1165 on southwest side of Jeptha Knob.
a=massive bed of unfossiliferous fine-grained "silty"-looking dolomitic limestone.
b=fossil breccia abounding in fossils of various Ordovician horizons and of the Brassfield formation.
c=coarse fragments of Brassfield rock and of dense very light-colored limestone.
d=dipping Eden beds in place with Dalmanella and Plectambonites.
x=best locality for collecting Brassfield fossils.

continuous for any distance, at least not individually. They seem to be very nearly absent from the larger part of the Silurian outcrop along the center of the Knob, whereas they increase rapidly, both in the thickness of the lenses and in the size of the rock fragments in them, as one proceeds from the center toward the margin of the structure. This can only mean that the source of the fragments lay near the periphery, not in the center of the disturbed area. The reason for this peculiar relation will become evident from the study of the structure of Jeptha Knob (see p. 224).

The color of the dolomitic limestone in some beds is reddish or pink instead of the normal buff or brownish tints. This is of some interest in view of the fact that in Jefferson County reddish colors in Silurian sediments are limited to the Brassfield and Osgood formations.

The dolomitic limestone normally forms massive ledges several feet in thickness. Such beds may show little or no trace of stratification and may tend to spall off in slices parallel with the surface of the spur. One such ledge seems to be fairly constant at an elevation of 1,090 feet to 1,100 feet.

From the relatively coarse-grained dolomite through nearly dense buff dolomitic limestones with increasing shale content there exist all transitions to layers of true shale. The shaly beds of dolomitic limestone, while massive when freshly exposed, break up into thin shaly laminae through weathering.

A typical section, the best in the Knob, is seen on the south side of the Knob road, a little over a quarter of a mile southwest of the highest point.

Chert, more or less in place.	
Buff, thin-bedded shaly dolomite and dolomitic shale	29 ft.
Covered	6 ft.
Buff, thin-bedded shaly dolomite (poorly exposed)	4 ft.
Covered	10 ft.
Buff massive, more or less distinctly bedded dolomitic limestone	5 ft.
Covered	5 ft.
Typical massive ledge of relatively soft buff dolomitic limestone spalling off	6 ft.
Rough massive ledge of hard dolomite, buff with brown specks	4 ft.
Covered or poorly exposed dolomitic limestone	13 ft.
Hard dense dolomite, light buff or light gray	5 ft.
(last 18 ft. probably slumped, passing into undoubted slump below.)	

In the normal dolomitic limestone, away from the fossil breccias, fossils are on the whole rare and consist only of molds. The following forms were collected.[8]

Camarotoechia indianensis (Hall).
Camarothechia sp., small globose form.
Platystrophia sp.
Hebertella sp.
Zygospira sp.

[8] The writer is indebted to Dr. Foerste for the identification of these fossils, to whom he wishes to express his sincere thanks.

This collection is too small to allow of definite conclusions concerning the age of the dolomite.

The fauna of the layers of fossil breccia, on the other hand, is wonderfully rich. Most specimens contained in it show the effects of wear. The fauna comprises practically every brachiopod, coral and bryozoan contained in the faunal lists of the Arnheim and Liberty as given in this report.

In addition to these, fossils of the Brassfield are found not infrequently. They are always associated with fragments of a coarsely crystalline, light gray or nearly white limestone. At first these fragments were considered evidence of a Brassfield age of the lower part of the dolomitic limestone, the writer expecting to find this characteristic Brassfield rock in place. No trace of it was, however, found in place. On the other hand, many fragments of it were seen in situ as conspicuous constituents of the breccia. Furthermore, the typical Brassfield fossils occur only in the layers of fossil breccia associated with the Ordovician fossils from widely different stratigraphic horizons. No trace of them has been seen outside the breccia lenses. We are forced to the conclusion that the matrix in which the Brassfield fossils and rock fragments are found is younger than the Brassfield formation.

The fragments of Brassfield rock are always associated with generally still larger fragments of a light gray, practically dense limestone which may represent the Saluda limestone of Jefferson County.

The Brassfield fauna found in the fossil breccia comprises the following species:

Enterolasma facetum Foerste.
Favosites sp.
Heliolites sp.
Lindstroemia gainesi (Davis).
Lyellia cf. thebesensis Foerste.
Lyellia sp.
Streptelasma geometricum Foerste.
Clathropora frondosa clintonensis (Hall & Whitfield).
Pachydictya bifurcata (Hall).
Pachydictya bifurcata instabilis (Foerste).
Phaenopora cf. multifida (Hall).
Rhinopora verrucosa Hall.

Leptaena rhomboidalis (Wilckens).
Orthis bucheri Foerste..[9]
Schuchertella daytonensis Foerste.[9]
Cyclonema daytonense Foerste.
Bumastus indeterminatus (Walcott).
Calymene niagarensis Hall.

For a correlation of the dolomitic limestone, it is necessary to take into consideration the fossil content of the overlying chert.

2. *The Chert*

The uppermost twenty to fifty feet of Jeptha Knob are thickly covered with loose angular pieces of light-colored chert. But the chert is not confined to the top alone. It forms thick colluvial masses on some of the spurs and forms low alluvial terraces in all valley bottoms radiating from the Knob. A veneer of chert is found several miles from Jeptha Knob on the slopes of some of the valley sides at places where its occurrence is a surprise to the geologist.

Linney, in his report on the geology of Shelby County in 1889, considered them to be "the broken fragments of the Corniferous hornstone." The fossils which are not infrequently found in the chert, prove a Niagaran age of the chert.

At a few places Linney's statement that the chert is "now in place near the top," can be shown to be correct; for instance, in the Knob road, below the highest point (1,139 feet), on the north side of the Knob. Even there the actual exposure of chert in place measures but a few square feet. Nowhere is the chert seen interbedded with limestone as most likely it was originally and possibly still is below the weathered surface. The fragments of the chert are platy in character measuring one to two inches in thickness.

The following list of fossils from the chert is based on materials collected by Prof. Arthur M. Miller of the University of Kentucky and the writer, and identified by Dr. Foerste who published an earlier list together with descriptions of new species in 1923.[10] In the list the new species are marked with an asterisk.

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*Described in "Notes on Medinan, Niagaran, and Chester Fossils." Denison Univ. Bull., Vol. 20, 1923.

[10]Foerste, Aug. F., "Notes on Medinan, Niagaran, and Chester Fossils," Denison University Bulletin, Jour. Scientific Laboratories, vol. 20, 1923, pp. 105-109.

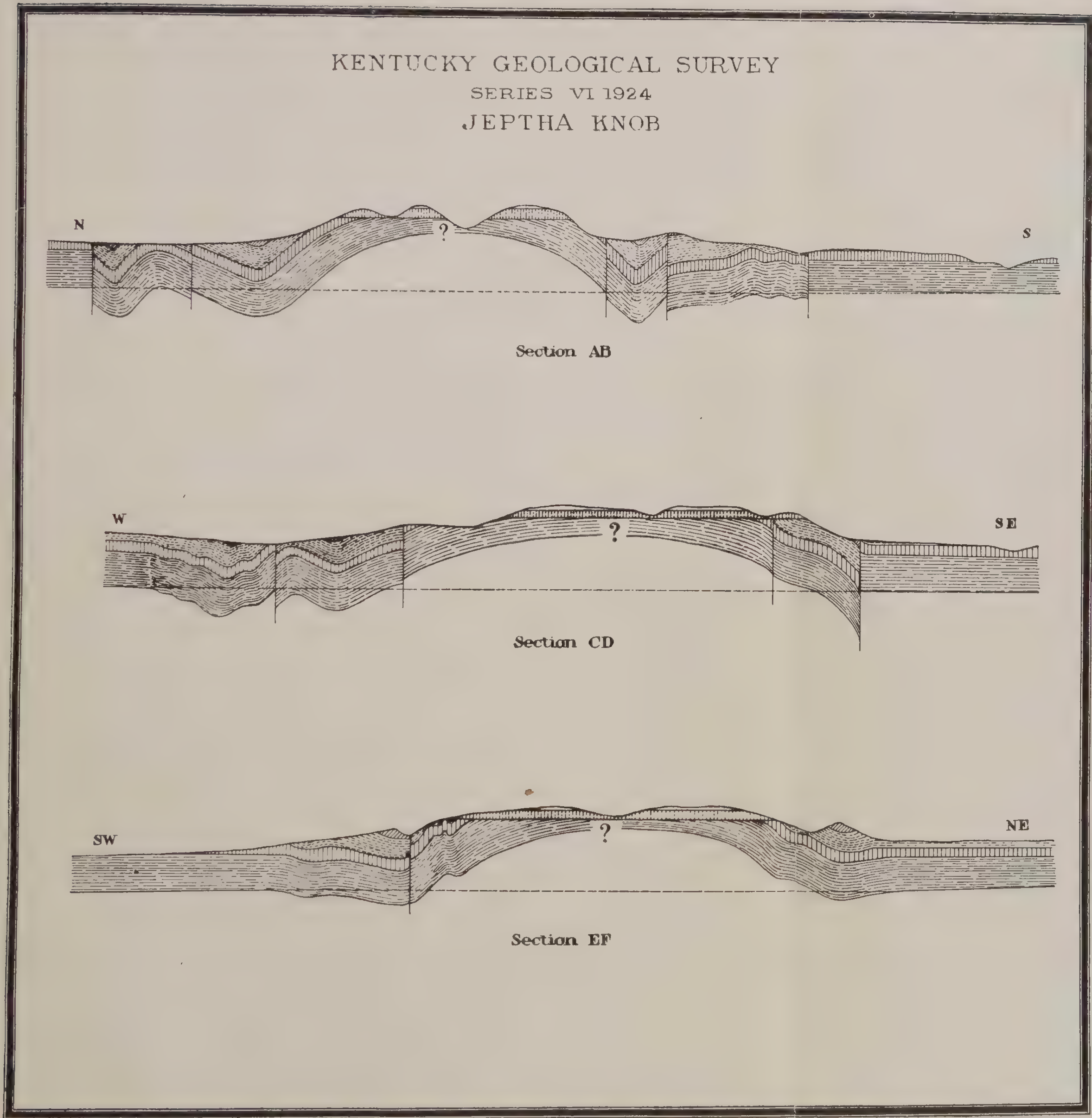


FIG. 6. DIAGRAMATIC STRUCTURAL SECTIONS OF THE JEPTHA KNOB.

Favosites favosus (Goldfuss).
Lyellia thebesensis Foerste.
Hallopora sp.
Pachydictya crassa Hall.
Pachydictya cf. bifurcata (Hall).
Camarotoechia indianensis (Hall).
Dalmanella elegantula (Dalman).
Dalmanella elegantula parva (Foerste).
Leptaena rhomboidalis (Wilckens).
Platystrophia daytonensis (Foerste).
Rhipidomella hybrida (Sowerby).
Schuchertella sp.
Stropheodonta sp.
**Strophonella cf. hanoverensis* Foerste.
**Strophonella milleri* Foerste.
**Cypricardinia jepthaensis* Foerste.
Hormotoma sublaxa (Conrad).
**Lophospira bucheri* Foerste.
Trochonema sp. (resembles *Tr. beloitense* Whitfield, but is much smaller).
Orthoceras, 3 species, one may be new, the others are unidentifiable.
Calymene cf. cedarvillensis Foerste.
Illaenus daytonensis Hall and Whitfield.

"Worm" burrows abundant on and in many slabs.

The large number of new species as well as the persistence of a number of species so far known from the upper Medinan (*Platystrophia daytonensis, Illaenus daytonensis, Lyellia cf. thebesensis*) give this fauna a peculiar character. No definite correlation can be based on it.

6. *Correlation of the Silurian Formations*

Dr. Foerste writes (loc. cit. p. 105):

"Since in the counties directly west of Shelby County, including Oldham and Jefferson counties, it is the Laurel member of the Niagaran which contains flat layers of chert in abundance, these Silurian chert fragments on Jeptha Knob are interpreted as also of Laurel age."

In that case the underlying 90 feet of dolomitic limestone would have to be correlated, at least largely, with the Osgood formation.

In Jefferson County, some twenty-five miles to the west, the thickness of the Silurian formations above the Brassfield is given by Butts as follows:

Louisville limestone	42 ft. to 100 ft.
Waldron shale	8 ft. to 15 ft.
Laurel dolomite	35 ft. to 40 ft.
Osgood formation	22 ft. to 30 ft.

If we accept Dr. Foerste's correlation, we must assume a considerable increase of thickness within these twenty-five miles. It would seem possible, however, that the more or less shaly dolomites below the chert are the equivalent of the three formations below the Louisville limestone. Their combined thickness in Jefferson County compares favorably with that observed on Jeptha Knob. It so happens that in his report on Jefferson County, Butts does not mention platy chert as in any way conspicuous in the Laurel formation. In the typical Jefferson County exposures the abundant chert layers do not seem to make their appearance until the Louisville limestone is reached. Again, in Jefferson County such corals as large-celled *Favosites* and *Lyellia,* which are not uncommon in the chert of Jeptha Knob, are not found in the Niagaran formations below the Louisville limestone. All these observations seem to suggest a possible Louisville age of the bulk of the Jeptha cherts.

But the writer is well aware of the uncertainty of correlations based on analogies of thickness, lithology, or general faunistic aspects. Much more collecting will undoubtedly greatly increase our knowledge of the chert fauna. In the meanwhile it will suffice to assign to the dolomitic limestone series a lower Niagaran age with the overlying chert not older than the Laurel formation and not younger than the Louisville formation.

STRUCTURE OF THE JEPTHA KNOB AREA

The folding and faulting of the vicinity of Jeptha Knob interrupts the gentle northwesterly dip which characterizes the rocks of Shelby County.[11] On the accompanying geological map the top of the *Strophomena maysvillensis* beds is seen to drop from an elevation of 850 feet in the southeastern corner to

[11]W. M. Linney, Reports on the Geology of Henry, Shelby and Oldham Counties. Ky. Geol. Survey, 1889 (?), p. 5.

about 815 feet in the northwestern, that is, in a distance of two miles. This gives an average dip of 22½ feet per mile, as is to be expected in rocks in this position on the western flank of the Jessamine dome.[12]

In the midst of nearly horizontal strata in which the dip is not apparent to the unaided eye in the average exposure, the steep inclinations seen in the strata wherever exposed, almost anywhere within a mile from the center of the disturbed area, form indeed a surprising contrast. The structure of which they are the expression consists of three distinct units. (See the accompanying map, Fig. 8, and cross sections, Fig. 6.)

1. A central area of uplift, exposing the Eden shales for a considerable distance.
2. A marginal belt of depression, marked on the geological map by the outcrops of the *Cyphotrypa* beds.
3. Outlying subordinate folds dominantly of anticlinal character, indicated on the map by narrow bands along which the *Strophomena maysvillensis* beds appear at the surface surrounded by little disturbed *Platystrophia* beds.

The Central Area

The center of the structure is occupied by the shale-limestone series of the Eden formation. Slabs covered with the often purplish-brown shells of *Dalmanella, Plectambonites,* or with delicate crinoid joints, or replete with the flat valves of *Rafinesquina* abound on the hillsides. Adequate exposures, however, are lacking entirely. The best, and one of the very few exposures, is found in the "Knob road" on the south side of Jeptha Knob. Figure 7 gives an idea of the varying attitude of the beds outcropping there. Similar variable dips and strikes are seen in the col north of the southwest spur of hill 1,165 feet (on the southwest side of the knob) and in casual small outcrops on the slope forming the east side of the same spur.

In the valley immediatly south of the letter "K" of "Knob," on the accompanying map, quite unexpectedly a few feet of barren shales become visible in the creek bed a short distance below the abandoned house, forming a miniature anticline

[12]Miller, A. M. "The Geology of Kentucky," Ky. Geol. Surv., Series V, Bull. III, 1919, p. 229.

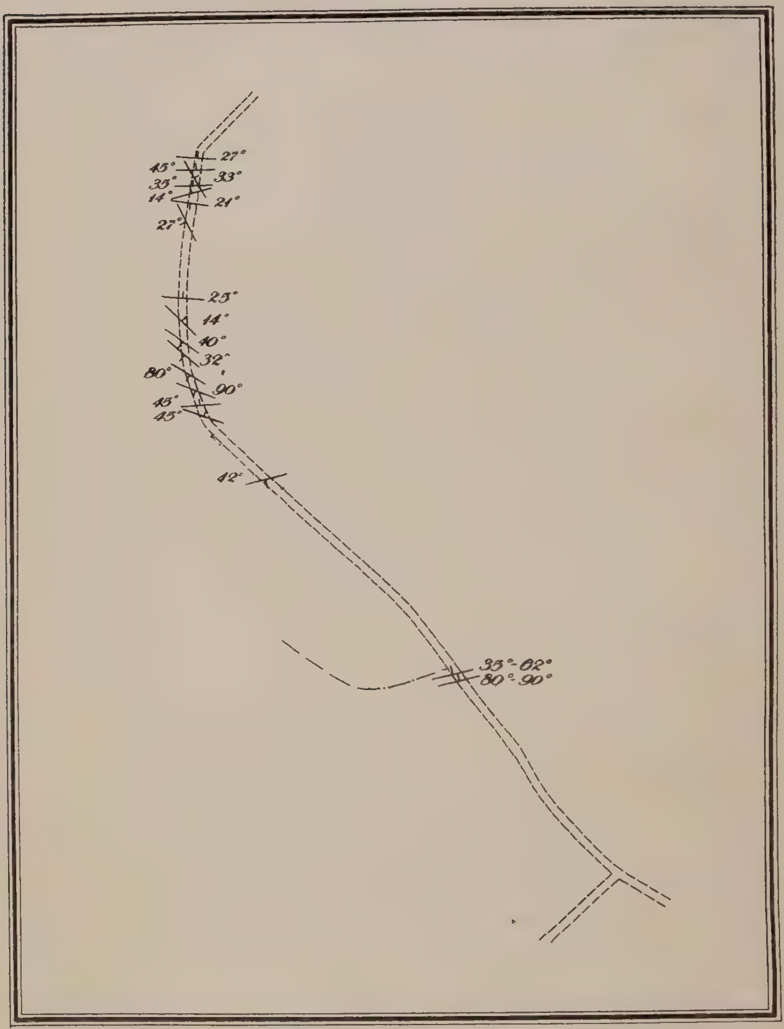


Fig. 7. Diagram illustrating the variability of strike and dip in a typical exposure of the Eden and Fairview formations. Knob Road, on south side of Jeptha Knob.

with dips over 30 degrees. Some of the gullies in the headwaters of the streams on the north and northwest sides of the Knob also give more or less doubtful glimpses of beds in place, some clearly dipping, others apparently level as, for instance, on the slope beyond the northwest point of hill 1,162 feet.

From such hopelessly fragmentary data it is impossible to obtain a correct picture of the details of the structure in this central area. On the whole, however, dips are neither steep nor consistent, and it seems quite probable that over much of the area the beds as a whole are not far from horizontal.

This view is in accord with the fact that no conspicuous synclinal bands of higher strata or similar anticlinal bands of conspicuously lower strata were found.[13]

Fragments of *Trinucleus*, which is abundant in the lower Eden beds, were seen only on slabs near the bottom of the valley which occupies the center of the north side of the Knob, at an elevation of about 960 feet, as would be expected if the structure did not involve large folds or fault blocks. Similarly, on the north side of the Knob, above the fault, along the Knob road, *Strophomena maysvillensis* is found consistently for such a distance as is possible only where no consistent steep dips prevail.

It appears probable, therefore, that in the central part of the structure gentle dips prevail, giving it the character of a flat dome.

As one approaches the edge of the central Eden outcrop, steep dips are seen on all sides. In the immediate neighborhood of fault lines, the beds are often vertical. The best exposures of such profoundly disturbed strata are found in the bottom of the deep gullies one-fourth mile south of the "ll" of the words "Clay Village" on the map. Another good illustration may be seen about one-half mile northwest of the letter "J" of "Jeptha Knob," where the *Platystrophia* beds lie nearly horizontal in the creek bed, while only a few feet on the south side of the valley *Dalmanella* beds outcrop in a northwesterly dip of 75 degrees. Similar sharp crumpling of these *Strophomena maysvillensis* beds on the margin of the central area and near a fault is well shown in the deep gullies on the southwest side of spur "A" of hill 1,165 feet and in the Knob road on the south side of the Knob, where the beds stand practically vertical along the fault.

It should be emphasized that the mapping of the *Strophomena maysvillensis* beds along the margin of the central area

[13] Minor synclines, carrying the **Dalmanella**-bearing lower half of the **Strophomena maysvillensis** beds down into the Eden shales, were recognized in fragmentary traces at several points, but could not be mapped.

is very incomplete and unquestionably partly inaccurate. The differentiation of these beds in the scattered and mostly weathered fragments of the float is most unsatisfactory, making it often impossible to differentiate them from the Eden.

If we include in it the outcrop of the marginal *Strophomena maysvillensis* beds, the central area may be described as showing roughly a six-sided outline. Four sides are unquestionably bounded by faults. It is quite probable that the other two sides are also largely defined by faults, but exposures are lacking almost completely, so that no definite proof of their existence could be given. The approximate position of the contact is, therefore, indicated on the map by a dotted line only.

On the whole periphery of the disturbed area there is but one locality at the extreme northern end of the disturbed area where the absence of faulting is definitely established.

Importance of the faults, however, must not be overestimated. Nowhere has a throw of over 200 feet been observed, while at most localities the throw does not exceed 100 feet.

Nothing definite is known concerning the attitude of the fault planes. Wherever contacts could be made out with sufficient accuracy, the points were found to form a straight line, whether in the valley bottom or on the spurs of the Knob. Wherever the evidence is sufficiently clear, it seems to prove that the position of the fault plane differs little from the vertical.

The Marginal Depression

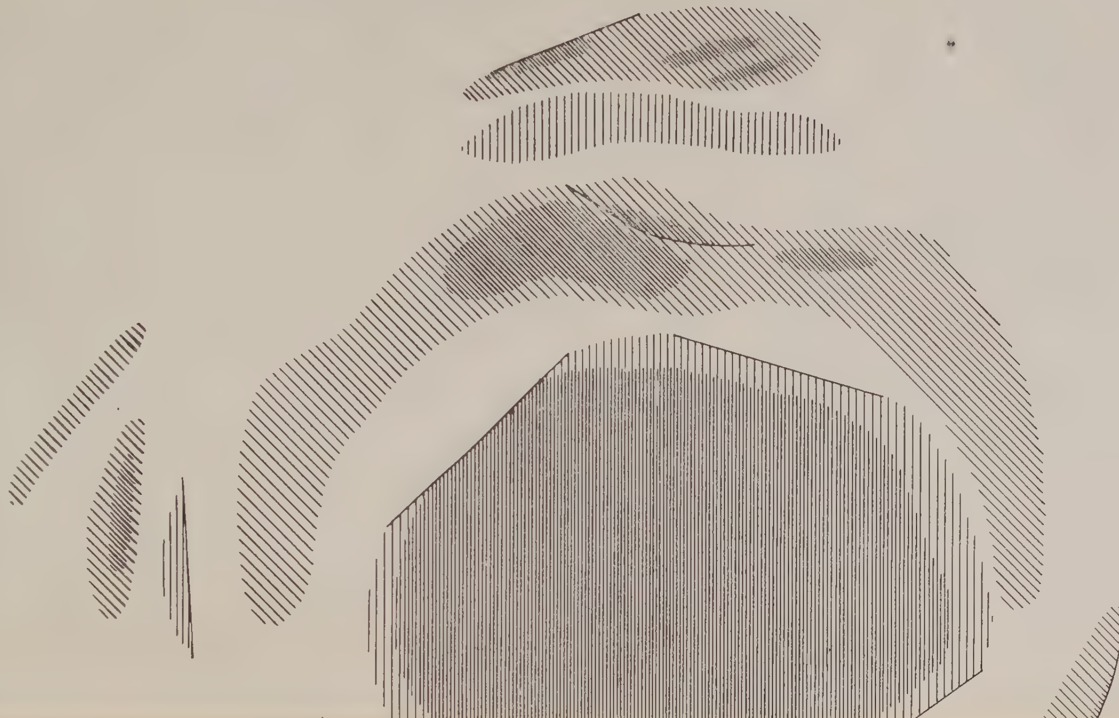
The few observed dips recorded on the map along the margin of the central area on the west side of the Knob make it appear as though the younger beds of the margin were dipping inward beneath the older Eden shales. It is most probable, however, that they represent accidental exposures of the west limbs of minor synclinal folds paralleling the margin of the structure. No evidence of overturning of folds and of a reversal of faults was seen, although special care was used in the field not to overlook any.

Varying dips carry the strata from the higher position on the margin of the central area below their normal level down to the axis of the marginal depression.

KENTUCKY GEOLOGICAL SURVEY

SERIES VI 1924

JEPTHA KNOB



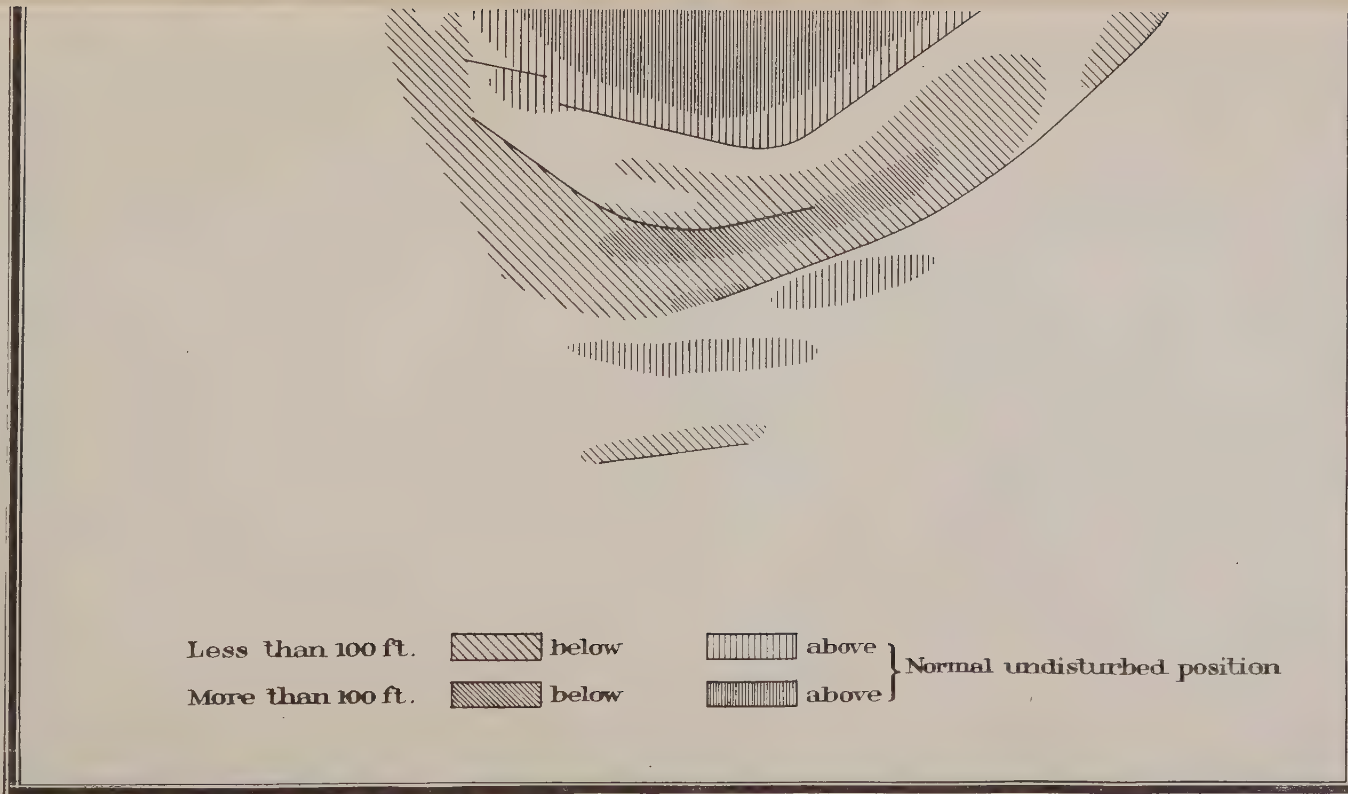


FIG. 8. AREAL DIAGRAM OF FAULT MOVEMENTS IN THE JEPTHA KNOB.

The data recorded on the geological map are not sufficient for a reliable contouring of the structure. On the accompanying structure sketch (Fig. 8) the areas which are definitely known to lie decidedly lower than normal have been represented by two degrees of shading. The sketch is necessarily generalized and does not reflect the minor undulations and irregularities which complicate the structure.

Thanks to the conspicuous lithological character of the *Cyphotrypa* beds, the broader outline of these depressed belts are readily recognized in the field. The presence of the heavy, pale, greenish to yellowish-gray rocks of limestone below 900 feet in a number of valleys on all sides of the structure is as striking as the slabs with *Plectambonites* and *Dalmanella* above 900 feet in the central area.

Fig. 8 shows that a peculiar crude symmetry appears to prevail in the distribution of the highest and lowest points along the axis of this marginal depression. At two opposite points the lowering of the beds is practically negligible, so that we may consider the marginal depression as interrupted at these points. In each of the two halves, on the other hand, the depression reaches a maximum at points which lie roughly on opposite sides of the structure.

In detail the marginal depression at many places is complicated by minor deformations, only a few of which are sufficiently well exposed to be represented on the map. Locally, also, the dips of the folds pass into faults, never, however, with a throw much exceeding 100 feet at best.

Outlying Folds

Outside the marginal depression sharp dips may still be seen on the north, west and south sides of the Knob, respectively. The structures of which they are a part are not continuous, but are, on the contrary, conspicuously local in character. They are, therefore, here distinguished from the marginal syncline as "outlying folds."

In each case the outward rise of the beds in the outer limb of the marginal syncline is continued beyond the normal level of the beds, and then abruptly reversed, producing an anticline in which the *Strophomena maysvillensis* beds are brought to the

surface. This chief anticline is followed outward by one or several minor folds through which the beds return to their normal position.

These outlying folds are the only parts of the whole disturbed area of which fairly good exposures exist, since here, at a distance of over a mile from the center of the Knob, the recent slight increase in the cutting power of the streams has bared the rock bed.

The folds north of the Midland Trail are particularly well exposed. Under the bridge, in the creek which flows through Clay Village, the dip of the south limb of the chief anticline is visible. Below this point for a distance, the creek-bed is choked with weeds and chert waste. It is advisable, therefore, to follow the dirt road which leads north from the bridge and with a right angle turn, leads back to the creek. Here, just below the point where it almost touches the creek, the upper beds of the *Strophomena maysvillensis* are shown in a fine exposure dipping over 30° to the south. At the north end of the exposure, the crest of the anticline is reached. Farther downstream northerly dips of 30° and even 50° are seen, and then the beds flatten out, becoming nearly level where the *Platystrophia* beds make their appearance on top. Again the dips steepen and twice the *Cyphotrypa* beds are carried down to the level of the creek bed, each time apparently cut off on the downstream side by minor faulting. Beyond the dirt road the *Platystrophia* beds are still seen dipping northwest with angles around 50°, exposed in a fine bluff. A short distance beyond, the *Strophomena maysvillensis* beds are found undisturbed.

A quarter of a mile below this point, the junction with another north-flowing stream is reached which crosses the Midland Trail three-quarters of a mile west of Clay Village, at the north end of the ill-famed "S" curve. Ascending the stream from this junction, one finds the *Platystrophia* beds ushering in the disturbance, dipping 20° south-southeast. The rapidly rising dip quickly carries the *Cyphotrypa* beds down to the creek level. Here several layers stand vertical. The axis of the syncline is soon passed and beneath the *Cyphotrypa* beds the *Platystrophia* beds reappear, dipping at first 80°. The dip decreases rapidly as the bridge is approached. Beneath the bridge the rocks lie

nearly horizontal, close to the crest of the anticline. South of the bridge the north limb of the anticline carries the strata down to the marginal syncline with rapidly increasing dip.

The exposures in Britton Creek, on the west side of the Knob, are less satisfactory. With several subordinate reversals of dip the *Platystrophia* beds in a little over a quarter of a mile descend low enough to carry down the *Cyphotrypa* beds with dips of 30° to 40°. They crop out conspicuously in the creek and in the road on the south bank. Before the road is reached, the axis of the syncline is passed and strong westerly dips bring the *Strophomena maysvillensis* beds to the surface, which may be seen on the south bank of the creek dipping approximately 45° west. They show for only a short distance, apparently being cut off sharply by a fault. Beyond it the *Platystrophia* beds occupy the creek bed with confused dips and strikes, possibly due to the influence of the dying out end of the fault which to the northwest bounds the central area.

Fig. 9. View of the east side of the valley of Wolf Run, seen from a point three-quarters of a mile northeast of Wolf Run schoolhouse. Shows two marginal folds and one fault.

Similar anticlines and synclines may be seen in the upper course of the creek flowing past Wolf Run School on the south side of the structure. Here twice the *Strophomena maysvillensis* beds are carried to the surface in anticlines. Fig. 9 reproduces a notebook sketch showing the well-exposed section of the northern one of these anticlines.

The local character of these outlying folds is their outstanding peculiarity. It is true that on the northeast side exposures

are almost entirely wanting within this critical zone, and that they are inadequate on the southeast side. The other two sides offer, however, ample exposures to prove that the localization of these outlying folds is real and not merely apparent due to the accidents of stream erosion.

Furthermore, these outlying folds accompany the marginal trough only where it reaches its greatest depth, as though the intensity of deformation outside the marginal ring depression were in some way dependent on the depth of downfolding within it.

On a previous page attention is called to the remarkable fact that the lenses of fossil breccia in the Silurian dolomitic limestones and shales become more frequent and the fragments in them larger as one goes outward from the center of the structure. We must, therefore, look for the source of the fragmental material near the periphery of the structure.

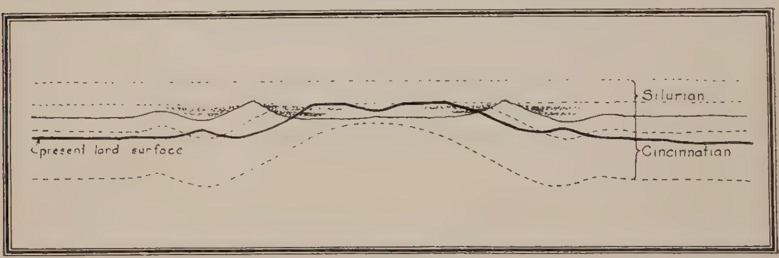


Fig. 10. Hypothetical cross-section showing the relation of the fossil breccias of the Silurian dolomites to the eroded structure of the underlying Cincinnatian rocks. The heavy line indicates the present land surface.

Figure 10 shows the probable topographic relations existing at the time of deposition of the breccias. When the deformation had come to an end, erosion rapidly destroyed the highest and profoundly fractured center of the uplift, as it invariably does in any anticline. As soon as the less resistant series of rocks below the *Cyphotrypa* beds became exposed, the progress of erosion was still more accelerated, until soon the worn down center was surrounded by a ring-shaped wall of synclinal structure.

This process is familiar enough under conditions of subaerial erosion. It is quite possible, however, that the Jeptha Knob mound of Silurian times was destroyed by the waves and currents of the Silurian sea, at least largely, if not wholly. The

absence of a basal breccia consisting of fragment of residual rock, such as is always present where subaerial weathering is in progress, seems to indicate that the play of waves and currents kept the surface clean, sweeping fragment after fragment out into deeper water beyond the area of this map. The distinct unconformity at the base of the Osgood beds in western Kentucky and southern Indiana indicates that the sea bottom for a time had risen above the "base level" of wave and current action. It is, of course, impossible to decide whether the Silurian Jeptha "mound" for a time was carried partly or wholly above sea level; but it is important to remember that an unconformity does not by any means indicate necessarily a withdrawal of the sea.

Sedimentation was resumed when the region again found itself below the base level of the average wave and current action. For a time waves and currents would spread fragments from the marginal reefs over the dolomitic muds of the sea bottom, until finally these muds covered the nearly planed down remnants of the marginal ridges.

The Age of the Structure

The undisturbed, practically level Silurian strata overlie the much disturbed older rocks with a striking angular unconformity. The remarkable basal fossil breccia has been described on preceding pages. There also the reasons have been given for the uncertainty concerning the age of the basal beds.

At least the lower part of the buff Silurian dolomite can be referred to the Osgood formation. There can be no doubt, therefore, that the disturbance occurred after the deposition of the Liberty and before Osgood time. If the writer's suggestion is correct that the Brassfield fossils and rock fragments found in the basal fossil breccia are secondary constituents like the Ordovician fossils, the disturbance must have taken place after (part of) Brassfield time and before (part of) Osgood time.

The central dome of the Jeptha Knob structure must have risen on the bottom of the shallow Silurian sea much like the salt domes of the Cenozoic rose above the bottom of the shallow waters of the western gulf coast. And the shortness of the time interval allowed for its formation reminds one, for instance, of the "post-

Lafayette, pre-Port Hudson'' age assigned to the coastal salt domes by Dumble.[14]

The Origin of the Structure

The Basic Facts

1. The parts of the structure, from the central dome through the marginal depression to the outlying folds, are so intimately connected and so visibly complementary, that the conclusion is inevitable that they are *all the result of one and the same disturbance.* It appears to be quite impossible, for instance, to make out any evidence for a period of domal rise distinct from an earlier or later period of depression.

2. A second significant fact is the *absence of fractures radiating from the center* of the structure. Radial cracks form wherever pressure is exerted at one point against plates of a brittle substance. While the term ''brittle'' may not be appropriate for limestone under the weight of a few thousand feet of rock, for slowly applied pressures, it would certainly be valid if the pressure had been applied suddenly. We are safe, therefore, in drawing the conclusion that the absence of radial cracks indicates that the forces involved in the deformation were not of an explosive character.

3. The study of the cross-sections and of Figure 8 leaves no doubt that the volume of the *raised portion of the structure exceeds that of the downfolded portion.* The structure is not merely the result of a shifting of materials. It can only be the result of an increase of volume. The size of the structure and the fact that it has persisted practically in its present form since Silurian time, make it seem probable that it is the result of a local introduction of substance at greater depth.

4. There is, however, a *complete lack of such phenomena* as would be expected if the distrubance were the direct result of *superficial volcanic activity.*

5. The structure is developed in a sedimentary series of which only the uppermost portion is accessible. The total thickness of the series is unknown. A rough estimate of the depth of the crystalline basement complex below the base of the Eden for-

[14] E. T. Dumble, "Origin of the Texas Domes," Bull. Amer. Inst. Min. Engrs., 143, 1918, p. 1635.

mation at Louisville is contained in Butts' report[15] on the "Geology and Mineral Resources of Jefferson County, Kentucky," to which the reader is referred for the detailed data. Butts estimates the strata of Trenton, Black River, and Stones River age at 1,075 feet, and the St. Peter and Beekmantown beds at 1,000 feet. Assuming these figures to apply also to this region, and adding 600 feet for the Cincinnatian strata up to and including the Liberty formation, we arrive at a *thickness of* 2,675 *feet* as a reasonable estimate of the thickness of the sedimentary series.

In its most general aspect, therefore, the Jeptha Knob structure may be described as a central mass of more or less angular outline and a diameter of roughly one mile, raised two hundred feet and more, surrounded by a ring-shaped depression half a mile wide of relatively smaller displacement. The whole structure set up in a sedimentary series of approximately half a mile thickness overlying the crystalline basement complex.

A Possible Origin

The structure may be interpreted as being the result of the slow rise of a column about one mile in diameter and cut from the underlying crystalline rocks by fractures on all sides, driven upward by an unknown force of deep-seated volcanic origin. Leaving the discussion of plausibility of this assumption to the end of this chapter, we proceed to picture to ourselves in as simple a fashion as possible the structural effects of such a disturbance.

If the fractures were extended vertically upward, a simple plug would rise bounded on all sides by normal faults, as shown in figure 11 (a).

If, on the other hand, the overlying sedimentary series were capable of retaining its continuity and stretching like a rubber sheet, the result would resemble the condition shown in figure (b), excepting the simple angularity of the lines of the diagram. It is obvious, of course, that the physical properties of the rocks in question would not permit of the formation of such hollow triangular spaces, not to speak of their capacity to stretch. It is equally obvious, however, that to fill the space of the trian-

[15] Charles Butts, "Geology and Mineral Resources of Jefferson County, Kentucky," Ky. Geol. Surv., Ser. IV, Vol. III, pt. 2, pp. 33-37.

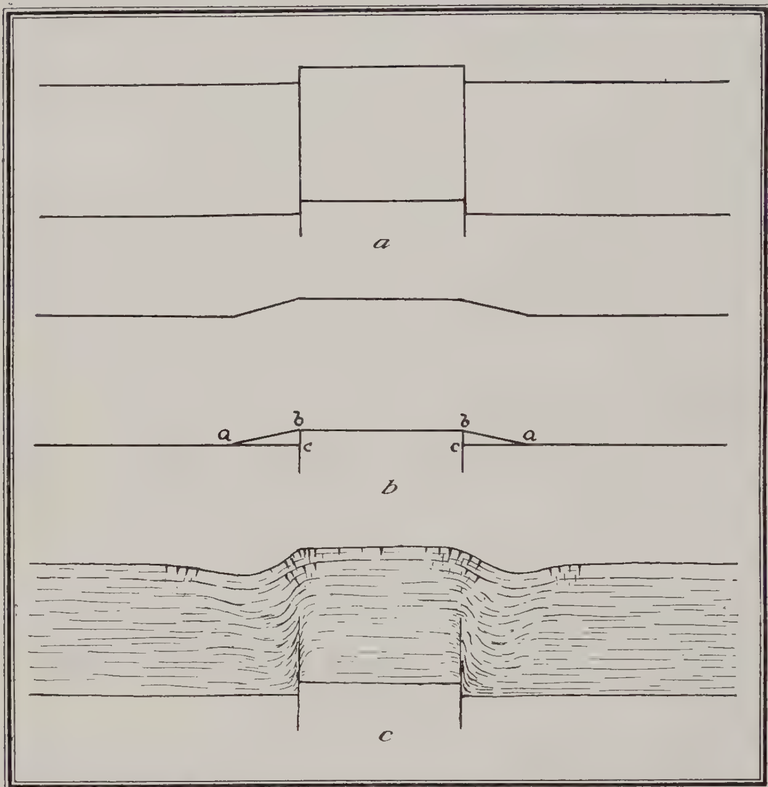


FIG. 11. SECTIONAL DIAGRAM JEPTHA KNOB

a. Diagram showing a raised block (plug) bounded by faults on all sides.
b. Diagram showing the imaginary case of a similar plug cut from the underlying crystalline basement and raised, lifting and stretching the overlying mantle of sedimentary rocks. Note the hollow space abc.
c. Diagram illustrating the interpretation of the underground structure of Jeptha Knob here suggested by the writer.

gular hollows, all of the material between *a* and *b* would be required.

In nature, on the other hand, we find that the raised portion is not bounded by sharp major fractures, but that a belt of deeply dipping rocks surrounds the raised center, distinctly lifted above its normal level by the drag of the center. For every particle held above its normal level by the "drag," there should exist a deficiency of equal volume beneath, unless it was filled by a transfer of rock bent and squeezed laterally into the places of reduced pressure alongside the slowly rising plug.

There is no question that if such flowage is at all possible it would not take place in the crystalline aggregate of silicates of the rising column, but in the much weaker limestones of the lower part of the sedimentary series.

The result of such lateral flowage below would be the depression of the surface on the outside of the rising dome (Figure 11 (c). In fact, all marginal structure would be understood to be due to the adjustment of the surface to the deeper-seated changes. On the whole the total volume of the depressed zone should equal that of the dragged up fringe surrounding the plug, not that of the whole "dome," a condition which seems to be fulfilled in the Jeptha structure.

The amount of drag may be expected to differ widely at different points along the circumference of the plug. Where it is greatest the marginal depression would be deepest and the adjustment it involves would affect the surroundings beyond the normal limits of the disturbance, producing "outlying folds."

Two fundamental objections must be met before we can consider the suggested mechanism plausible.

1. We are not accustomed to consider limestone capable of flowage under the action of gravity alone and under confining pressures measuring but a few thousand pounds per square inch. We must remember, however, that many observations prove that even at the surface the elastic limit of rocks "is lower than the brief experiments would lead one to suppose,"[16] and that the rate at which the pressure is applied is one of the fundamental factors which determine whether a solid will deform without fracturing.

Two examples will illustrate the point. In the State lot of the cemetery of Jefferson City, Mo., Winslow[17] observed a slab of "white, crystalline limestone or inferior marble," 6 feet long, 3 feet wide and 2 inches thick, which in the 25 years it had been lying supported only by four cornerposts, had sagged nearly 1½ inches, or about 1/50 of the total length or about 1/35 of the distance betwen the supports.

[16] G. F. Becker, "Finite homogenous strain, flow and rupture of rocks." Bull. Geol. Soc. Amer., Vol. 4, 1893, p. 52.
[17] Arthur Winslow, "An Illustration of the Flexibility of Limestone," Amer. Jour. Sci., Vol. 43 (Ser. 3), 1892, pp. 133-134.

A similar slab of Trenton limestone, 6′ 6″ by 2′ 10″ by 3¾″, was recently described by Kindle[18] from the cemetery at Hull, P. Q. In not more than 77 years it has sagged 1½ inches. "In other words, a slab of Trenton limestone 3¾ inches thick and 266 feet in length could in a period of 75 years or less be bent into a circle if subjected to a stress no greater than its own weight."

Between such observations[19] and laboratory experiments lasting minutes instead of years and involving containing pressures equivalent to many miles of rock, lie possibilities which may well cover the requirements of our hypothetical case.

2. The other difficulty lies in the assumption of a plug of crystalline rock pushed into the overlying sediments. It is difficult to picture the conditions under which such a plug would become detached from the crystalline basement; and the necessity of invoking the mechanism of magmatic intrusion to account for its upward movement, is disturbing in view of the total absence of volcanic activity in Kentucky during early paleozoic time.

Yet the assumption is not unreasonable. In the Serpent Mound structure in Adams County, Ohio, an analogous structure mapped by the writer,[20] with twice the diameter of its Kentucky counterpart and more readily recognizable rock formations—the mechanism of the central uplift can be studied to better advantage. There the uplifted center is more irregular in shape than that of Jeptha Knob appears to be. Its outline shows, however, the dominating influence of two directions which correspond to those of the two joint systems characteristic of the whole region. In the Serpent Mound structure, therefore, the blocks that constitute the raised center, seem to have yielded to the pressure of the rising magma along pre-existing joint planes. In fact, it is reasonable to think that the existence of a point of exceptional weakness, probably due to the intersection of unusually strong joints, made possible the whole disturbance.

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[18] E. M. Kindle, "An Example of Gravity Deformation in a Limestone Slab." Canadian Field-Naturalist, Vo. 35, 1921, pp. 115-116.

[19] Similar occurrences have been described by Gillman, Hobbs and others.

[20] Manuscript in course of preparation.

The same may well have been true in the case of the Jeptha Knob structure. The rising magma, reaching within a mile or so of the surface, may have found such a place where strong intersecting joints in the crystalline rocks circumscribed a block that could be detached and lifted up bodily.

An attempt has been made at the beginning of this chapter to show that the marginal depression and the outlying folds may be explained as the direct consequence of this uplift of a rigid block into sediments capable of flowage. In this respect the Serpent Mound structure differs greatly. There the depression greatly exceeds in volume the central elevation. The assumption seems unavoidable that at greater depth material was withdrawn or shrinkage took place on a scale only known otherwise in regions of active volcanism. Should proof be brought forth that under the conditions prevailing at Jeptha Knob no such amount of flowage can take place in limestones as is assumed in the suggestion offered above ,corresponding movements of magmatic materials would have to be postulated here also.

In Adams County, Ohio, as well as in Shelby County, Kentucky, the existence of an intrusive igneous body in depth is purely hypothetical with not one single petrographical observation to support it. Fortunately we can point to a third analogous structure of which practically the same can be said, but which has been proven to be connected with a concealed intrusive. It is the "Steinheim basin" of Southern Germany which lies in the midst of the little disturbed strata of the Jura Plateau some 19 miles southwest of the well-known "Ries" basin near the boundary of Wurtemberg and Bavaria.[21] Its diameter is only 1½ miles, but like the American structures, it possesses an uplifted center and a broad marginal depression. A thick cover of Tertiary fresh water sediments conceals most details of the structure. For this "Steinheim basin" Branca and Fraas[22] coined the term "cryptovolcanic structure." The complete absence of volcanic materials at Steinheim and their practical insignificance in the much more remarkable "Ries" basin were as much a puzzle to the German geologists as the

[21] See Richard Lepsius' "Geologische Karte des Deutschen Reiches in 27 Blaettern," 1:1,500,000, Sect. 23.

[22] W. Branca and E. Fraas, "Das Kryptovulkanische Becken von Steinheim," Abh. Kgl. Preuss. Akad. Wiss., 1905.

similar American structure is to us. In 1902, K. Hausmann[23], by extended magnetic observations in the region comprising the two structures, proved the presence of a basic intrusive at an average depth of about 5 km. (3 miles). It is to be hoped that our own Geodetic Survey will find it possible to conduct a similar investigation in the vicinity of at least one of our two cryptovolcanic structures.

The nearest and almost the only known center of active volcanism in the Appalachian region during early Paleozoic time is indicated by beds of Bentonite, a decomposed rhyolitic ash according to Larsen, which are found in the Middle Ordovician of Tennessee, Kentucky and Alabama and have recently been described by Nelson.[24] Its exact location is still entirely a matter of conjecture. It lay, however, certainly not less than 150 miles from Jeptha Knob and probably much farther. There is no evidence whatever that its activity extended even into Upper Ordovician time. The nearest volcanic activity during Silurian time, to the writer's knowledge, is found in the tuff and lava beds of Maine and the adjoining part of Canada.

With evidences of volcanic activity thus almost lacking in the whole east of the United States during the time in which the Jeptha Knob structure came into existence, it is but natural that we should be reluctant to take recourse to volcanic forces to explain it. The only comparable structures formed without the direct aid of volcanic forces known to the writer, are the salt domes of Texas and Louisiana, southern Mexico, northwestern and southeastern Europe, India, Algiers, and other countries. All can be understood as "offshoots of bedded salt deposits, formed and forced upward by pressure in a semiplastic condition."[25]

To the best of our knowledge, however, no rock salt or any other substance of similar plasticity under stress is known to underlie the sediments of Shelby County, and, for that matter, the whole Jessamine dome. Nevertheless the possibility of local lenses of rock salt is not to be denied in the deepest part of the

[23] K. Haussmann, "Magnetische Messungen im Ries und dessen Umgebung," Abh. Kgl. Preuss. Akad. Wiss., 1904.

[24] Wilbur A. Nelson, Bull. State Geol. Surv. Tenn., Bull. 25, 1921, pp. 46-48.

[25] G. Sherburne Rogers in the valuable review of the literature on salt domes: "Intrusive Origin of the Gulf Coast Salt Domes," Econ. Geol., Vol. 13, 1918, pp. 448-485.

sedimentary series which has been reached by the drill in only very few places. The high salinity of the "rank salt and sulphur water which is known as Blue Lick water" and is so persistently found in the lowest levels reached by the drill, gives color to this possibility. Should salt actually be responsible for the structure, its action would be essentially equivalent to a substitution of salt for lava, as far as the mechanism of the upper part of the disturbance is concerned. So long as the existence of salt is as problematical, if not improbable, it would be futile to devote space in this discussion to the question of the source of the pressure causing the rise of the salt, the relation of the marginal depression to the movement of the salt and so forth.[26]

Economic Significance of the Structure.

The ubiquitous interest in oil and gas has been focused repeatedly on Jeptha Knob. The possibility of the presence of oil or gas in commercial quantities can not be absolutely denied, but it must be considered most improbable in view of the fact that the formations in question have so far yielded little more than traces of both substances.

From the nature of the structure, it is evident that the chances for an escape for both substances are very great. It is possible, however, that the plastic Cincinnatian shales, especially the Eden shales, have effectively sealed fractures wherever they formed. Fortunately there is no evidence of erosion having cut through this mantle of sediments at any point.

If we grant effective sealing of such hydrocarbon contents as may be present, the question of the best location of a test well presents several possibilities.

a. Commercial quantities of either may be contained in porous layers in the crest of the structure, provided the doming is on the whole simple.

b. Production may be found in the strongly dipping beds of the drag belt, corresponding to the "lateral sands" or "deep

[26] A perusal of such literature on the salt domes of the Coastal Plain as was immediately available to the writer, disclosed not one case in which a marginal synclinal ring was clearly recognized. It would seem, however, possible that investigations, especially with the drill, were discontinued as soon as the steep dips of the margins of the salt plugs were reached, and the marginal complications of the structure overlooked or disregarded. The writer shall give more attention to this point in his report on the Serpent Mound structure now in preparation.

sands'' of the Gulf salt domes, where they abut against and presumably are sealed by the massive limestone beds of the assumed plug.

c. Should, against all probabilities, the center contain a true salt core, the possibility exists that there is a porous ''cap rock'' that plays so conspicuous a role in the Gulf salt domes.

d. The smallness and apparently superficial character of the marginal outlying folds, would make them appear unsuited for the formation of ''pools.''

To test the structure, at least two holes should be drilled: the first at or near the center; the other at a carefully selected point in the marginal belt of steeply dipping beds.

In view of our complete ignorance of the nature and possibilities of the lowest members of the sedimentary series, an attempt should be made at least in the central hole to drill down to the crystalline basement which may be expected at a depth not much exceeding two thousand feet unless salt or igneous rock intervenes.

Physiographic Notes on the Jeptha Knob Area.

Jeptha Knob rises as a monadnock above the average level of 900 feet of the Lexington peneplain. This means that here the infinitesimally slow process of regional denudation which causes the surface of the land to waste away, has been retarded. We must know the factors responsible for this delay, if we are to understand the form as well as the structure of the Knob.

Jeptha Knob is located on a spur of the major divide which separates the waters draining westward into Salt River from the much shorter streams which flow eastward into Kentucky River. Stream erosion is least effective near the headwaters of drainage systems. But the major divides as such have long been reduced to the general level of this old plain. While this location, of course, favors in a general way a retardation of the process of wearing down, the factors that have lead to the preservation of Jeptha Knob must have been strictly local and inherent in the structure.

Aside from climatic factors which for obvious reasons need not concern us here, the rate of surface denudation depends largely on the effectiveness of unconcentrated wash.[27]

[27] Fenneman, N. M., "Some features of erosion by unconcentrated wash," Jour. Geol., Vol. 16, 1908, pp. 746-754.

Porous beds, even if not particularly resistant to the action of frost and running water, retard the process of denudation, because they reduce the amount of run-off. Similarly, synclines are apt to divert ground-water away from the stream channels, weakening the streams and thereby retarding the rate of downcutting. A combination of both, that is, porous rocks of synclinal structure, invariably resist the leveling forces longer than any other structures, giving rise to plateaus, mesas, and residual hills.

Let us now picture to ourselves the vicinity of Jeptha Knob at the time when the last remnants of the Silurian rocks were being removed from the major divides by the relentless progress of denudation. We have no reason to assume that up to that time the spot where Jeptha Knob now stands, formed a hill any more than any other point of the growing Lexington peneplain. It did not prove different until the dipping beds of the underlying structure became exposed. Then the marginal synclines which surround the central uplift on all sides, began to exert their influence. When freshly uncovered, they comprised in the upper part not only the *Cyphotrypa* beds, but also the Liberty and Saluda formations, all three more permeable and more resistant to the forces of erosion than the lower horizons. It is the writer's conviction that this wall of more porous and more resistant rocks of synclinal structure protected the center with its remnant of the capping Silurian, causing the survival of Jeptha Knob as a residual hill on the Lexington peneplain. To the writer this explanation seems adequate, although data to test it quantitatively seem to be lacking.

Linney had assumed that the vicinity of Jeptha Knob as a whole had been depressed in such a way as to leave "a basin-like depression by which the surrounding surfaces were, for a while, protected against erosion." The evidence for such a depression, sufficiently large to produce the desired effect, would have to be sought in the elevation of the Silurian strata of Jeptha Knob in comparison to those farther west.

We take Linney's geological map of Shelby County and draw a line from the center of Jeptha Knob through Shelbyville to the point where Floyd's Fork crosses the boundary of Jefferson County. This line we continue on Butts' map of Jefferson

County to the bluffs overlooking the Ohio River south of Harrods Creek.[28]

Along this line, from the bluffs of the Ohio River to the county line, we find the base of the Osgood formation rising 215 feet in 9 miles, that is, 24 feet per mile. From the county line to Jeptha Knob it rises 430 feet in 20 miles, or 21.5 feet per mile. This latter value is almost identical with that recorded in the immediate vicinity of Jeptha Knob. The flattening of the dip from 25 feet per mile to 21.5 feet is nothing more than the normal change to be expected upon approaching the axis of the Jessamine dome. It can certainly not be construed as indicating a pronounced local depression.

The marginal synclines still influence the topography of Jeptha Knob. The remnants of the protecting wall stand out conspicuously on the topographic map as ridges lying transverse to the normal drainage which is directed radially outward from the center. The most striking examples are the curved ridge extending southeast from Clayvillage, and the prominent ridge, trending southwestward, on which the Hemp Ridge road runs for three-quarters of a mile, on the southwest side of the Knob.

On the inside, these marginal transverse ridges are accompanied by streams which for some distance also flow in a tangential instead of the normal radial direction. The creek which flows through Clayvillage, Wolf Run, Britton Run, each for some distance flows on the inside of such a transverse, one is tempted to say "hogback," ridge.

Since the rejuvenation of the Lexington peneplain, erosion has been going on actively. The latest physiographic change is represented by the low terraces of rock waste which fill especially the upper portions of all valleys. Most recently the process of aggradation of which these waste terraces are the result, has given way to renewed erosion. In 1866, when Mr. Sam Newton of Clayvillage bought this farm, which comprises a part of the Knob, one could cross the streams at most any point in a wagon. Much of the Knob has been cleared since that time. The result

[28] The line used here is drawn as nearly at right angles to the strike of the Silurian formations on the flank of the Jessamine dome as possible. A study of the structure contours on Butts' map will show that this line in Jefferson County avoids the large local deformations such as the Lyndon syncline and the Springdale anticline.

DEPARTMENT OF THE INTERIOR
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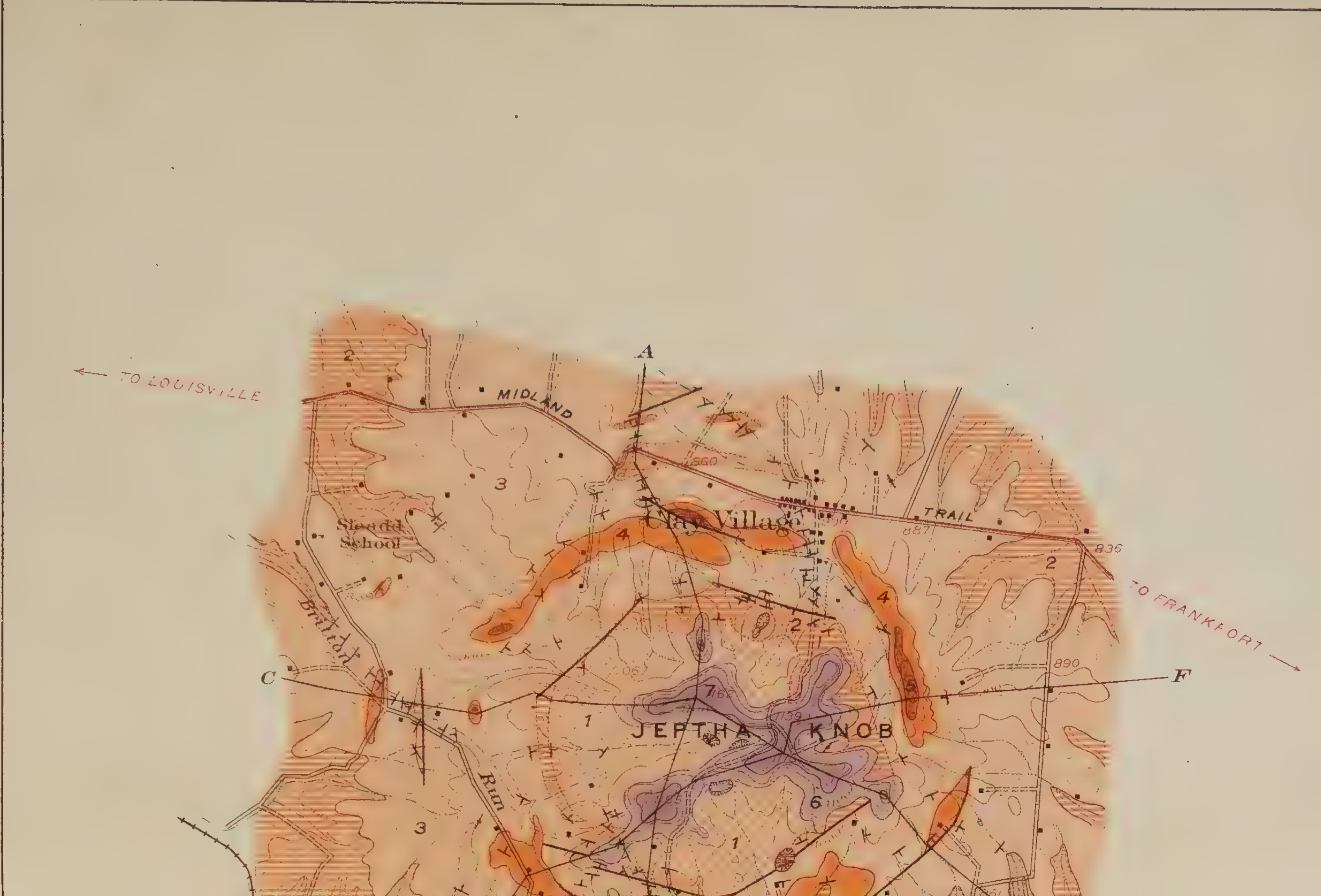
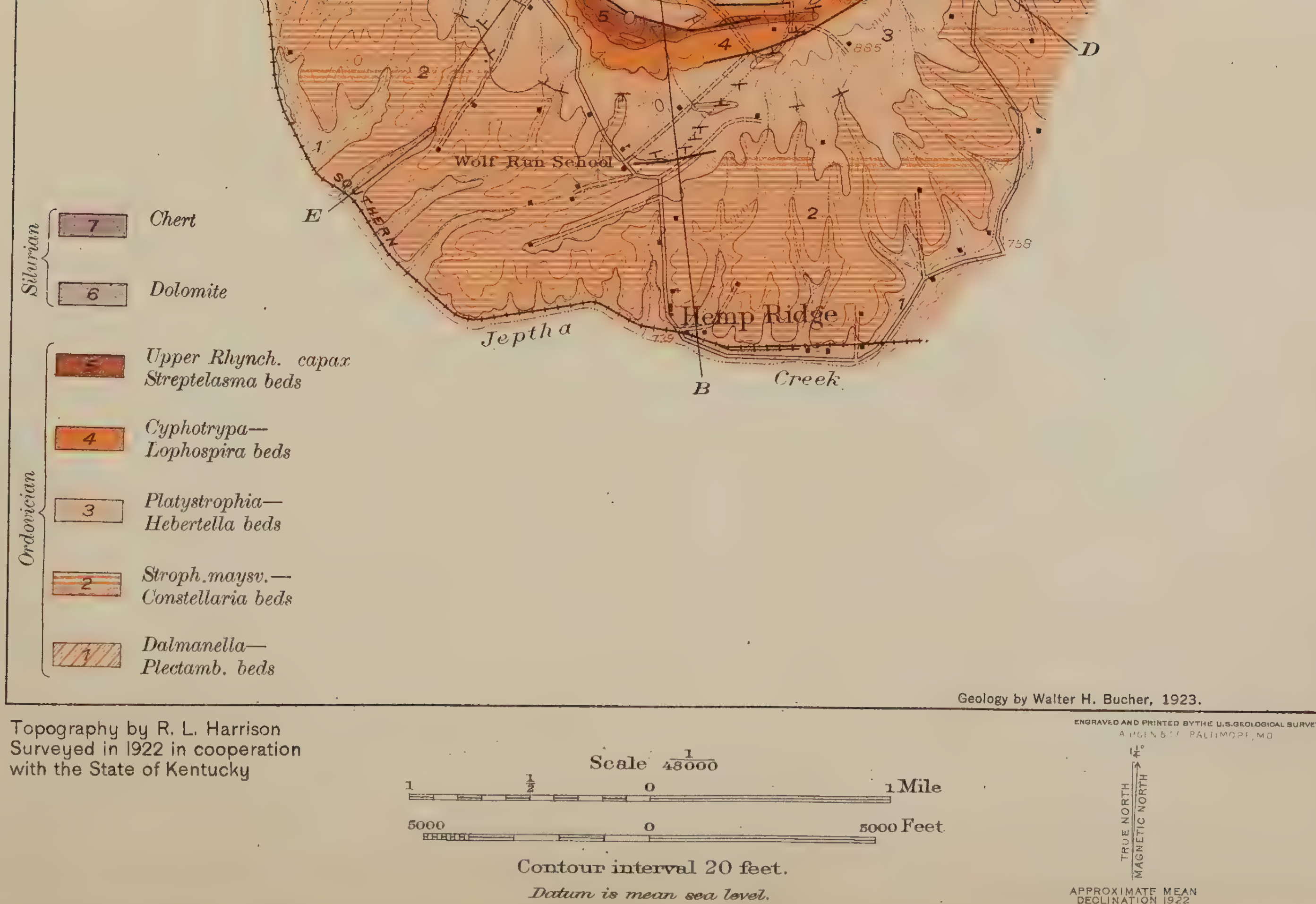
KENTUCKY
(SHELBY COUNTY)
JEPTHA KNOB AREA




Wolf Run School
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Silurian
7 Chert
6 Dolomite
Ordovician
5 Upper Rhynch. capax Streptelasma beds
4 Cyphotrypa—Lophospira beds
3 Platystrophia—Hebertella beds
2 Stroph. maysv.—Constellaria beds
1 Dalmanella—Plectamb. beds
Geology by Walter H. Bucher, 1923.
Topography by R. L. Harrison
Surveyed in 1922 in cooperation
with the State of Kentucky
Scale $\frac{1}{48000}$
1 Mile
5000 Feet
Contour interval 20 feet.
Datum is mean sea level.
ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1922

is that "within the last twenty years the creeks have washed out so deep that one has to make a crossing to pass over." A similar relation between deforestation and stream rejuvenation has been recorded from many places in the Ohio basin.[29]

Two observations on soils may close this account of the Jeptha Knob area.[30]

The deepest residual soils of this region are found on the *Platystrophia-Hebertella* beds. Where they dip strongly, the thickness of the soil may reach 7 to 8, even 10 feet. Along the rootlets of plants the brown soil is generally bleached to a pale greenish gray tint. Where a sufficiently large number of minute rootlets have penetrated the soil, it may have lost its brown color entirely and, where the roots have decayed, may look quite deceiving.

At some points, the iron and manganese content of the soil has collected in the form of small brown or black nodules, $\frac{1}{4}$ to 1 inch in diameter.

Strong dips, of course, favor the formation of exceptionally deep soil on all formations of this area. The deep soil is generally betrayed by excessive gullying.

Finally one peculiarity of the chert-filled soil of the top of Jeptha Knob deserves special mention. To any one who has seen the bare surface of this soil early or late in the year, it is a surprising sight to see these chert slopes covered with an excellent crop of corn or wheat. The abundance of rock fragments and the exposed position would "make a body think the land would fire easily and be droughty." The exact opposite is the case. The writer was told repeatedly that even in dangerously dry weather the soil will be found moist only a short distance below the surface. The capillary properties of the chert seem to enable it to store moisture successfully, so that with a yield of an average of fifty bushels of corn per acre and of fifteen to twenty bushels of wheat the rock wastes of the top compete successfully with the best bottom lands.

[29] For instance: C. R. Stauffer, G. D. Hubbard, and J. A. Bownocker, "Geology of the Columbus Quadrangle," Geol. Surv. Ohio, 4th Ser., Bull. 14, 1911, p. 106; N. M. Fenneman, "Geology of Cincinnati and Vicinity," ibid., Bull. 19, 1916, p. 160.

[30] For a technical description of the soils of Shelby County, with a soil map, see C. Van Duyne, L. R. Schoenmann, S. D. Averitt, "Soil Survey of Shelby County, Kentucky," U. S. Department of Agriculture, in "Field Operations of the Bureau of Soils, 1916," Washington, D. C., 1919.

INDEX

E.

F.

G.

H.

I.

J.

K.

L.